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ALC LAN Network Interface Unit System Performance Report

By

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This document reports on the investigation of network channel performance characteristics for the Air Force Logistics Command Air Logistics Center local area network interface units. A scaled broadband network was used to examine channel loading capacities and end-to-end delay under various load conditions. The percentage of loading, as a measure of carrier on time, and the resultant end-to-end delay are identified. Traffic characteristics that stressed the network channel performance are also identified. Testing also characterized the carrier sense multiple access with priority acknowledgement protocol used in the TRW network interface units.

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SECTION 1

INTRODUCTION

Since 1982, the Air Force Electronic Systems Division (ESD) and The MITRE Corporation have supported the Air Force Logistics Command (AFLC) in developing and implementing local area networks (LANs) at the AFLC Headquarters located in Dayton, Ohio and five Air Logistics Centers (ALCs) located in Warner Robins, Georgia; San Antonio, Texas; Oklahoma City, Oklahoma; Ogden, Utah; and Sacramento, California. ESD was assigned overall responsibility for system acquisition with MITRE designated as the general system engineer.

1.1 BACKGROUND

AFLC has undertaken the task of updating, augmenting and replacing many of its data processing and communications facilities under the auspices of the Logistics Management Systems (LMS) modernization program. More than 150 systems will be modernized under this program. A limited number of these will be substantial data processing systems at several sites with significant communications requirements. These systems have been identified as the baseline LMS. A LAN is being installed at each of the AFLC ALCs to support the LMS modernization program. The terminals and printers of these systems will communicate with host computers through the LAN.

In September 1985, TRW Systems Engineering and Development Division (SEDD) was awarded a contract to implement the LANs at the five ALCs. The LANs, which will provide basewide data and video communications for the LMS at the ALCs, are unusually large. Each LAN spans 25 to 85 buildings, in some cases located miles apart. About 20,000 outlets are being provided on each LAN to support approximately 7000 user devices. These LANs are an order of magnitude larger than any currently in operation.

Various subcontractors are installing the cable plants in a series of five blocks of interbuilding trunking and intrabuilding cable plants. TRW Information Networks Division (IND) has provided the network interface units (NIUs). The NIUs on contract consist of commercial off the shelf (COTS) asynchronous NIUs, synchronous NIUs, and bridge units.

The ALC LANs include numerous terminals and printers distributed across the many buildings on each base. Users working on the large, centrally located database management systems must access multiple hosts from single terminals. Many of the candidate systems for connection to the LANs either have not been procured or the hardware has not been selected. This has led to some uncertainty about the use of the LANs, the amount of traffic loading, and the amount of growth expected in the short- and long-term life of the LANs. Even now, after most of the cable plants have been installed and some LMS programs have been connected, the work load and specific numbers of terminal/host types are largely unknown.

In 1986, in support of the ALC LAN architecture, TRW developed an analytical model to predict the performance of the LANs under specified loading. Since the actual system could not be tested because it was not fully installed, analytical models or simulations were the only tools available to predict network performance. Analytical models are feasible only with the use of highly simplified assumptions. Even then, analytical models can model only a limited number of variables present in the actual system. Furthermore, model results are highly dependent on the accuracy and comprehensiveness of the assumptions. The critical issue for the ALC LANs was whether the statistical nature of the network communication protocol would drive the number of required network channels beyond the number recommended in the analytical model. A larger number of channels would impact the cost and complexity of the system.

MITRE recommended a set of tests to examine this issue because the fidelity of the TRW SEDD analytical model did not adequately characterize the statistical performance of individual network channels based on the traffic described in the system specification. Although this testing was outside the scope of the ALC LAN contract, TRW agreed to proceed with MITRE's recommendation. This led to TRW SEDD, TRW IND, and the MITRE Corporation collaborating on a series of NIU performance tests to understand the performance characteristics of the asynchronous and bridge NIUs and their impact on the system architecture.

1.2 SCOPE OF DOCUMENT

This document reports on the investigation of network channel performance characteristics for the ALC LAN asynchronous and bridge NIUs. A scaled broadband network was used to simulate ALC LAN network environments to examine channel loading capacities and end-to-end delay behavior under various traffic load conditions. Testing also characterized the carrier sense multiple access (CSMA) with priority acknowledgement protocol used by the TRW IND NIUs.

Section 2 states the overall test goals. Section 3 describes the traffic characteristics assumed in the tests. Section 4 defines the test phases, their objectives, test configuration, test composition, and approach. Section 5 summarizes the test results. The last section presents conclusions.

SECTION 2

TEST GOALS

A system performance test was conducted to refine the existing analytical model to better predict system performance. The goals were threefold:

a) to characterize the NIU protocol (because it was not well documented);

b) to determine channel capacity;

c) to determine how sensitive channel capacity is to various types of traffic.

In addition, an effort was made to develop tools for predicting network performance for various types of traffic.

SECTION 3

TRAFFIC DESCRIPTION

Each of the ALC networks are required to support interconnection services for 5600 terminals, 1120 printers and 6720 host computer ports. Multiple data channels will be needed to handle the expected traffic from this large number of devices. Most of the traffic on the LAN will be either terminal-to-host or printer-to-host with only a minimal amount of traffic expected between terminals or workstations. A large amount of the traffic will be to and from a large, centrally located computer center. Given the large physical size of the LANs and resulting long propagation delays, users will be divided into subnetworks to optimize performance. To provide universal connectivity, large numbers of bridge NIUs will connect the users operating on different channels or in different subnetworks. The performance of NIUs and bridges under load is critical to the assurance of efficient operation of the LANs. This section defines the seven types of traffic, the system specification and the word processing traffic, used in the simulation of system performance.

3.1 SYSTEM SPECIFICATION TRAFFIC

The ALC LAN System Specification defined the traffic load for each LAN based on the number and type of probable devices located at each ALC. This load model specified traffic in four types to correspond with the devices that were expected to operate on the LANs at the ALCs. The load model also stated the amount of traffic that would need to be bridged from one subnetwork to another.

The traffic was divided into two categories: terminal traffic and printer traffic. The terminal traffic was expected to be transactional, since most of the baseline LMS are database management applications that will evoke transactional traffic on the LAN. It was assumed that 75 percent of the terminal traffic would be between the terminals and the host computers located in the computer center. The remaining 25 percent of the terminal traffic would be distributed randomly on the LAN.

The printers were expected to be medium speed line printers. Printer traffic was specified to be one-way from a host or workstation to a printer. Printers were to be distributed randomly about the LAN.

The system specification, therefore, defined four types of traffic: Type I - echoplex transactional terminal; Type II - line-oriented transactional terminal; Type III - echoplex data entry terminal; and Type IV - printer. The following paragraphs describe the four types of traffic.

3.1.1 Echoplex Transactional Terminal Traffic

Echoplex transactional terminal traffic is defined as Type 1. This type of traffic represents an implementation of transactional traffic on echoplex devices such as asynchronous ASCII terminals or workstations in asynchronous emulation mode.

Type 1 terminal traffic is characterized for a transaction every two minutes during a 75 percent duty cycle Each transaction consists of the transmission of 80 bytes of data from the terminal to host in echoplex mode followed by a full screen echoplex response of 1920 bytes of data from the host to the terminal. It was expected that up to 1400 Type 1 terminals would be connected to the LAN at each ALC.

3.1.2 Line-Oriented Transactional Terminal Traffic

Line-oriented transactional terminal traffic is defined as Type 2. This type of traffic would be typical of most block-mode asynchronous terminals and almost all synchronous terminals.

Type 2 terminal traffic is characterized by a transaction of 80 bytes every two minutes during a 75 percent duty cycle. After the 80 byte block has been successfully transmitted to the host, the host responds by transmitting 1920 bytes of data to the terminal. Type 2 traffic is similar to Type 1 except that the transactions are not echoplex. It was expected that up to 2800 Type 2 terminals would be connected to the LAN at each ALC.

3.1.3 Echoplex Data Entry Terminal Traffic

Echoplex data entry terminal traffic is defined as Type 3. This traffic is typical of a data entry operator typing non-stop into an echoplex terminal at a rate of 30 words per minute (wpm).

Type 3 terminal traffic is characterized by a 360 byte echoplex transaction every two minutes during a 75 percent duty cycle. This translates to three characters every second where each character must be echoed from the host before it is displayed at the terminal. It was expected that up to 1400 Type 3 terminals would be connected to the LAN at each ALC.

3.1.4 Printer Traffic

Printer traffic is based on a medium speed line printer that receives and prints two million bytes of data per hour while active 50 percent of the time. The two million bytes of data is about 500 pages on a printer operating at 400 lines per minute. It was expected that up to 1120 of these printers would be connected to the LAN at each ALC.

3.2 ADDITIONAL TRAFFIC

Three additional traffic transaction types were defined during the course of the testing to explore the effects of and sensitivity of performance to traffic that might be encountered at the ALCs, but which had not been included in the system specification. These traffic transaction types represent components of a typical word processing environment. They are based on TRW IND's observations of individuals in typical office environment.

TRW IND observed secretaries using word processing software packages executed on a host computer. Each secretary was allocated a terminal which could display up to 80 characters per line, 24 lines per screen. When a hard copy of a file was needed, the user spooled the document file to a printer that printed on single 8.5" by 11" sheets of paper. The printer also had sufficient memory to buffer one page of text. All terminals and printers were connected to the host computer using 9600 bit per second (bps) asynchronous connections. Each user was sufficiently familiar with the basic operations to perform all word processing functions.

TRW IND observed that a typical word processing task began with data entry into the computer from a hand written transcript. Once data entry was completed, the file was spooled to a printer for a hard copy proof. The users primarily worked on memoranda and short documents with an average length of five pages of 60 character lines printed on a standard sheet of paper. The hard copy was then reviewed and edited by its originator. The marked-up copy was returned to the secretary, the document file revised, and the final copy printed.

Word processing users divided their time, on average, among three modes:

a. DATA ENTRY consumed 50 percent of an active user's time. This mode involved entering text from the keyboard of a terminal. The terminal operated in echoplex mode.

b. EDITING was performed 25 percent of the time. Users would page through a text file to the desired screen of text, and then move the cursor to the location requiring editing. Editing typically involved insertion of text or spelling corrections. However, paging through the document to proof text was also considered editing. The average editing rate was one full screen of text per minute at the terminal.

c. IDLE TIME, the time the user was not actively typing at the keyboard, accounted for 25 percent of the user's time.

It was also noted that in an office environment, word processing users had various skill levels. Observed differences between users included general facility with the word processing software, familiarity with specific word processing functions, typing speed, and typing accuracy. Of these, typing speed would significantly affect the traffic load. Therefore, it was necessary to divide the word processing users into two types, average users and power users.

An average user was one who typed at 40 wpm. This rate offered a load of 4 characters per second (cps) to the network. Seven out of eight users were classified as average users. Collectively, seven average users printed seven documents over a 75 minute period.

Power users, the remaining one user out of eight, typed at a rate of 60 wpm. This rate offered a load of six cps to the network. One power user printed one document every 60 minutes.

To develop the additional traffic transaction types, it was assumed that four of the eight word processing users would be engaged in data entry tasks and the other four in editing tasks. Furthermore, it was assumed that nearly all of a user's idle time would occur during editing rather than during data entry.

During the 50 percent of the time spent in edit/idle mode, users performed two functions: cursor movement (scrolling and paging) and data entry. The load which resulted from scrolling was estimated as twice the load due to data entry since scrolling was performed by continuously depressing a cursor movement key which automatically repeated at ten cps. Therefore, if half of the edit/idle cycle created a load which was twice the data entry load, and the other half created no load, then the average load for edit/idle tasks was equal to the load for data entry. The load which resulted from paging created a significant additional load.

Thus, the eight user activities were considered equivalent and a single scenario was used to emulate the data entry and editing functions of each member of the group. Separate traffic transaction types for paging and printing were developed. The word processing environment was therefore divided into three types of traffic: data entry, paging, and printing. The following paragraphs define the three additional types of traffic.

3.2.1 Data Entry Traffic

Data entry traffic represents 80 percent of the population. To simplify the traffic, the power user and average user data entry loads were merged into this single type. This group offers continuous five cps —rounded up from 4.25 cps — echoplex traffic between a terminal and a host at one second intervals during a 50 percent duty cycle.

3.2.2 Screen Refresh Traffic

Screen refresh traffic represents 10 percent of the population. In an actual word processing environment, a terminal transmits a three character escape sequence when the page up/down key is pressed at the keyboard. Upon receiving this sequence, the host computer transmits a full screen of text. A full screen of text is 24 lines of 73 characters per line for a maximum 1752 characters. Therefore, this group offers three cps from the terminal to the host. The host responds by transmitting a continuous burst stream of 1752 characters. This traffic is processed at 60 second intervals during a 25 percent duty cycle.

3.2.3 Printer Traffic

The observed printers could not print at the rate of 960 cps (continuous 9600 bps stream), and regular flow controls to throttle the data rate were observed. The printers all had sufficient memory to buffer a page of text. The typical traffic pattern was a burst of data (a page); a pause while the printer flow controlled to catch up with printing duties or to wait for a page to be ejected from the printer, and the next page fed; followed by the next burst of data (the next page). The maximum page size was 60 lines of 73 character text.

To determine the rate at which users could offer print jobs, it was necessary to look at the two types of users, the average user and the power user. The power user could enter a 5 page document every 3650 seconds, thereby offering one document an hour to the printer. The average user could enter a five page document every 5475 seconds, thereby offering 0.7 of a document every hour. The offered print rate for the group of eight users is 5.9 documents an hour or about one document every ten minutes. If the printers operated at a continuous rate rather than in one page bursts, this would be equivalent to 36 cps. Instead, it was necessary to derive the load in the following way:

Capacity of 9600 bps line = 960 cps
Offered load = 5.9 documents/hour = 129,210 char/hour = 35.9 cps
Duty cycle = 35.9 cps/960 cps = 3.7% = ~4%
Page Tx duration = 4380 char/page/960 cps = 4.6 sec = ~5 sec

It was assumed that the printer traffic represents ten percent of the population. Printers offer a continuous stream of 4380 characters every five seconds during a four percent duty cycle.

SECTION 4

TEST PHASES

This section describes the three test phases: NIU protocol characterization, network external load evaluation and end-to-end delay performance, and NIU parameter sensitivity evaluation. The tests used the asynchronous and bridge NIUs.

The testing derived quantitative information on network channel performance for the ALC LAN NIUs. The tests were defined and conducted by the test team consisting of TRW SEDD, TRW IND, and MITRE. MITRE contributed the test plan/procedures and the end-to-end delay software program to perform the end-to-end delay testing. TRW IND developed the specific procedures used during the testing, set up the scaled broadband network, and provided the necessary test equipment. All three parties participated in the conduct of the test; all test events were recorded by TRW IND in an engineering notebook.

4.1 NIU PROTOCOL CHARACTERIZATION

The ALC LAN NIUs (excluding the bridge NIU) use a non-persistent CSMA protocol with priority acknowledgement for communicating over the broadband network. Microprocessor based NIUs perform the required protocols to maintain virtual circuits over the network. The NIUs use vestigial side-band amplitude modulation encoding data at two million bps (Mbps) with the Non-Return to Zero Inverted (NRZI) with zero insertion scheme.

The bridge NIU is essentially a packet filter which selectively passes packets from one channel to another with destination addresses that are within the specified range set in the bridge. All virtual circuit support is passed transparently through the bridge NIU.

NIU packet formats are unique to the TRW IND implementation of this protocol. Each packet can be separated into five different parts: leading flags; header field; 0 to 256 byte information field; CRC; and trailing flags.

4.1.1 Objectives

There were four main objectives of the NIU protocol characterization test:

a) to characterize the packet transmission of different packet types (the number of leading flags, length of packet contents, and number of trailing flags);

b) to measure the packet transaction timing (data transmission lengths, the acknowledgement transmission lengths, and the acknowledgement window size);

c) to measure the mean packet transfer latency through the network bridge (the amount of time it takes to pass the packet from one side of the bridge to the other side);

d) to measure the 'Ack reserve' feature of the bridge (the amount of time the bridge waits for the acknowledgement to return through the bridge).

4.1.2 Test Configuration

Three configurations were used to perform the protocol characterization tests; two included a bridge NIU and one did not. These configurations are shown in figures 4-1, 4-2, and 4-3. The figures also show the test equipment required. All measurements were taken using a network configuration unloaded with other traffic.

4.1.3 Test Composition

Eighty-six test measurements were taken to characterize the NIU's protocol. The packet information listed in table 4-1 was collected as noted for packets with 1, 96, 192, and 256 characters in the information (data) field.

Table 4-1. Protocol Characterization Test Data

Packet Information	Data Characters per Packet 1	96	192	256
Data Packet and Acknowledgement	X			X
Data Packet	X	X	X	X
Data Packet AGC Burst	X			X
Data Packet Leading Flags	X			X
Data Packet Information	X			X
Data Packet Trailing Flags	X			X
Data Packet Carrier Turn-off	X			X
Acknowledgement Window	X			X
Acknowledgement Packet AGC Burst	X			X
Ack Reserve (Configuration C Only)	X			X
Acknowledgement Packet Leading Flags	X			X
Acknowledgement Packet Information	X			X
Acknowledgement Packet Trailing Flags	X			X
Acknowledgement Packet Carrier Turn-off	X			X

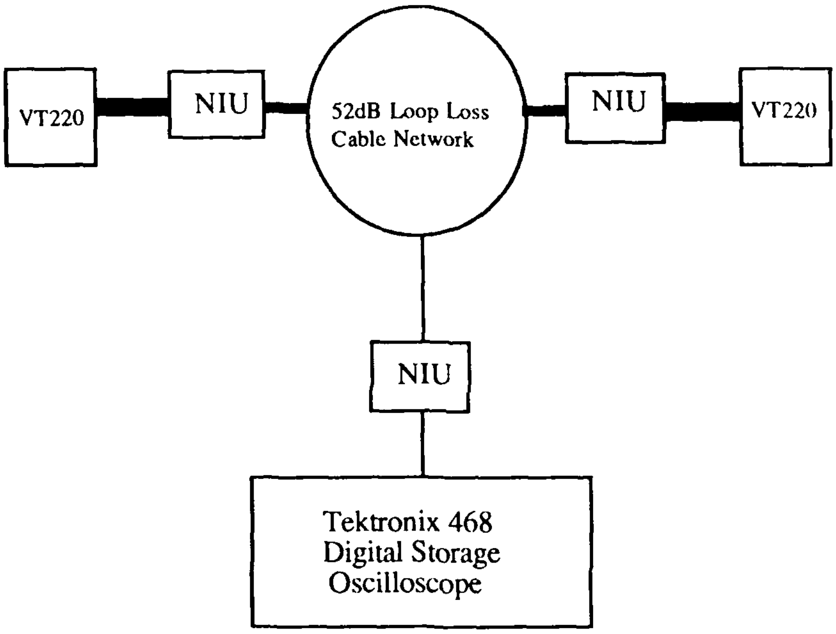


Figure 4-1. Protocol Characterization Configuration A

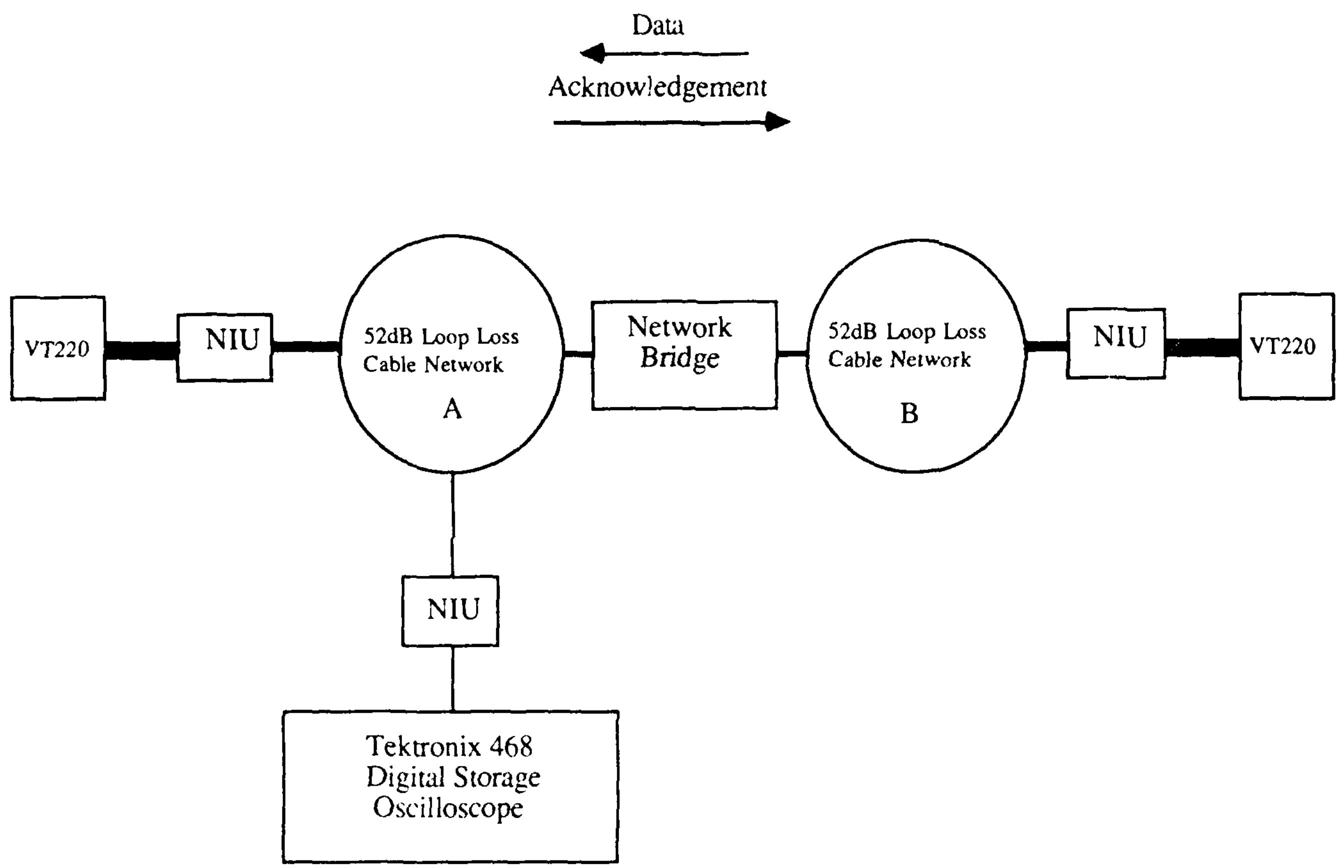


Figure 4-2. Protocol Characterization Configuration B

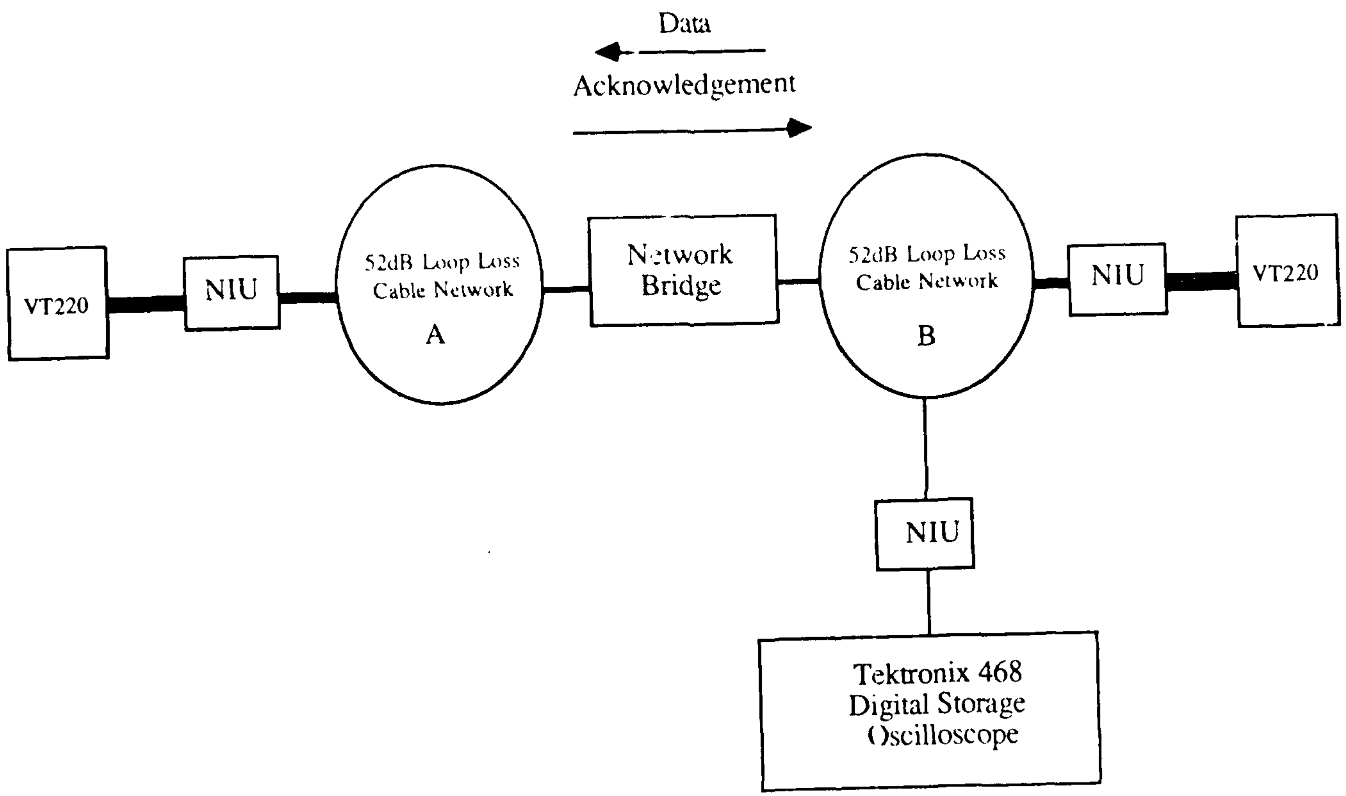


Figure 4-3. Protocol Characterization Configuration C

4.1.4 Approach

To generate the desired packet size, the buftime parameter setting (the parameter that controls the number of data characters contained in each packet) was changed from its default value. It was necessary to do this each time a different packet size was tested to allow 1, 96, 192, or 256 character packets to be sent over the network. Once the buftime parameter was set, a virtual circuit was established and testing could begin. Separate photographs and duration measurements were taken for each size data packet. All other NIU default parameter settings were used during the characterization tests. The bridge NIU's address switches were set to allow the test packets to pass through the bridge.

4.2 LOAD EVALUATION AND END-TO-END DELAY PERFORMANCE

These tests provided a vehicle to measure the channel loading and resulting delays based on various traffic transaction types and mixes of traffic transaction types. This set of tests measured the channel loading of the four types of ALC LAN traffic transactions and the three types of word processing environment traffic transactions observed by TRW IND.

4.2.1 Objectives

The objectives of the test were threefold:

a) to collect network load characteristic data as it relates to the incremental addition of virtual circuits to the network;

b) to show the maximum sustainable channel load;

c) to collect data on the one-way end-to-end delay time experienced during increased amounts of channel load.

Data was collected for various traffic transaction types and traffic transaction type mixes.

4.2.2 Test Configuration and Special Equipment

A testbed containing 544 NIU ports was created. Half of these ports were dedicated to the load generators that provided the network traffic transmissions based on the traffic transaction type or traffic mix of interest. The other half of the ports were dedicated to the transmission of the traffic on the network; these ports were driven by the load generators to which they were connected. A maximum of 136 virtual circuits could be made using the 544 NIU ports.

In addition to the NIUs, the network contained a number of taps and cables. Figures 4-4 and 4-5 show the testbed configuration. Since the network's sole function was to evaluate traffic loading, no propagation delay or noise was built into the configuration.

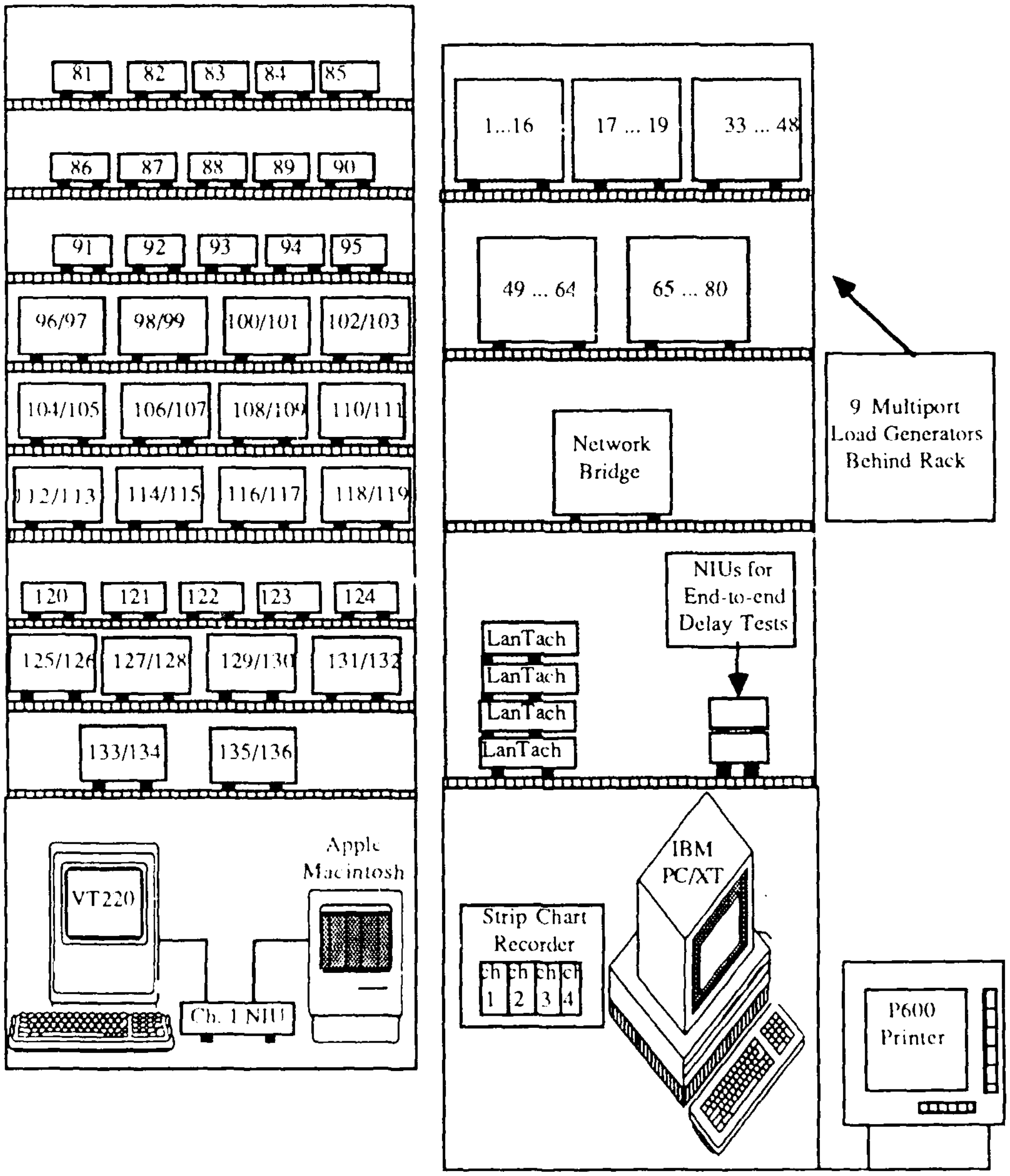


Figure 4-4. Network Performance Testbed Configuration

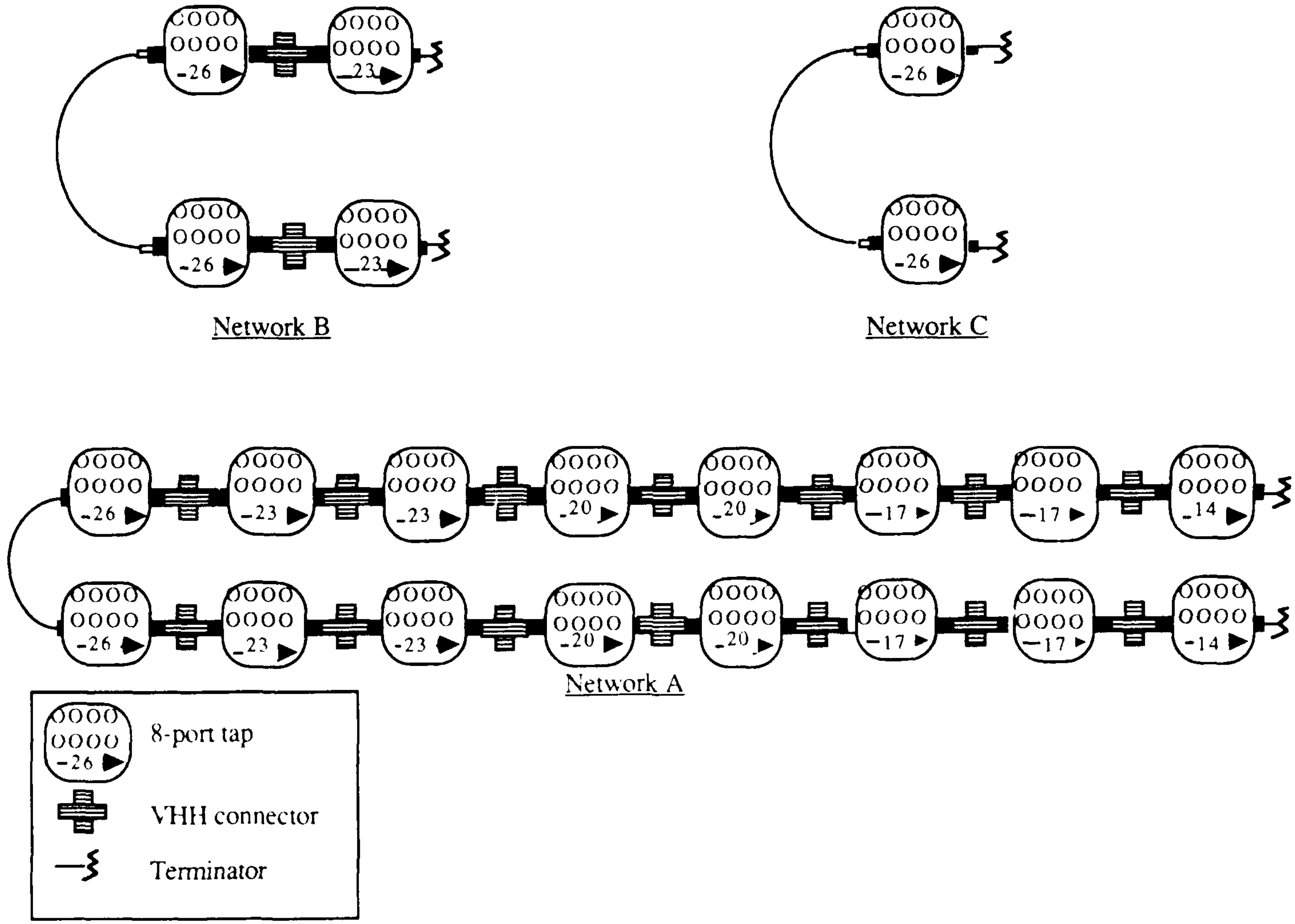


Figure 4-5. Network Test Configuration

The specific load and end-to-end delay testing was performed using unbridged, bridged, and cascade bridged network configurations. Figures 4-6 through 4-9 show the configurations for each of the tests. The two bridged network configurations were not configured to offer traffic from the bridged network side. Only the local network side would offer traffic to the network.

4.2.2.1 Load Generator

A load generator was developed using a standard NIU with the software modified to simulate asynchronous activity at the test NIU RS-232 ports. Figure 4-10 shows the load generator equipment setup. The load generator operated on a different channel to avoid affecting the network. One load generator port was required for each test NIU port in the network. One, out of the two load generator ports needed to support a virtual circuit, was programmed to be the "master" that controlled the network activity across the virtual circuit. The other load generator port was the "slave." The master would initiate the traffic and command the slave to receive and/or transmit, and to echo or not echo the master's transmissions. The load generator would thus allow half or full duplex, echoplex or simplex exchanges.

The master load generator was configured to generate the traffic transactions desired over the network. The load generator stored up to ten different traffic scenarios at any one time. A scenario was defined by six parameters assigned to it -- namely, Duty Cycle, *BurstTx*, *BurstRx*, *Echoplex*, *CharRate*, and *Cycle Time*. These parameters were defined in the following way:

Duty Cycle defined the frequency of repetition of a given scenario cycle. Periods of activity and inactivity within a given cycle were randomly distributed by a pseudo random number generator.

BurstTx defined the number of characters transmitted from a load generator master to a slave during a given cycle.

BurstRx defined the number of characters transmitted from a load generator slave to a master during a given cycle.

Echoplex defined the number of characters the slave would echo back to the master during a given cycle. If the Echoplex value was less than the BurstTx value, the slave would echo characters to the master starting with the first character transmitted, until the echoplex value was reached.

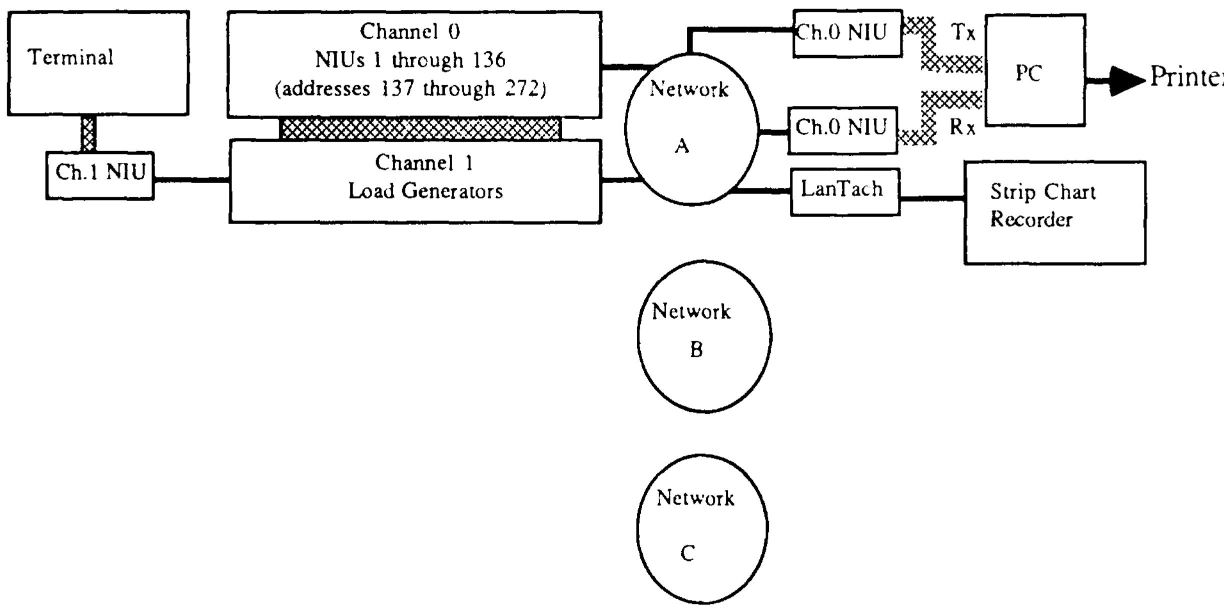


Figure 4-6. Unbridged Test Configuration

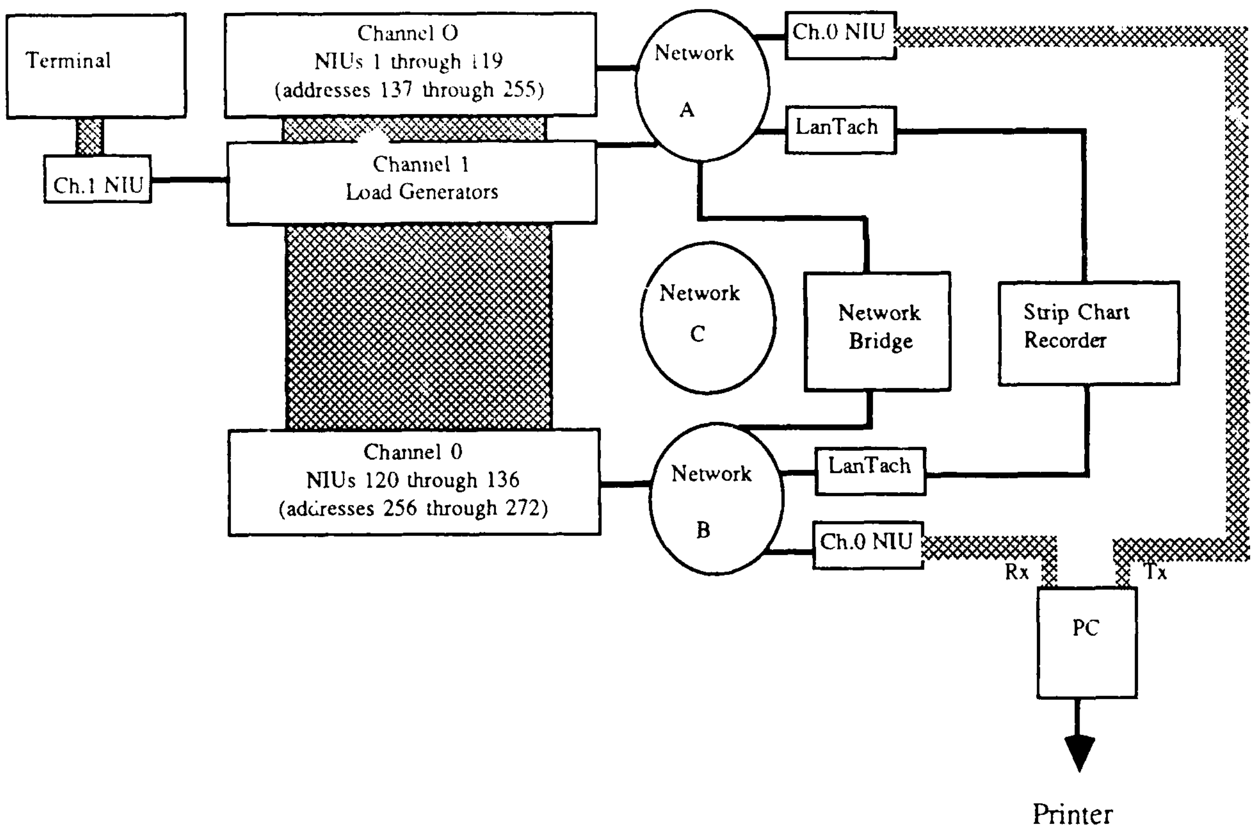


Figure 4-7. Bridged Test Configuration

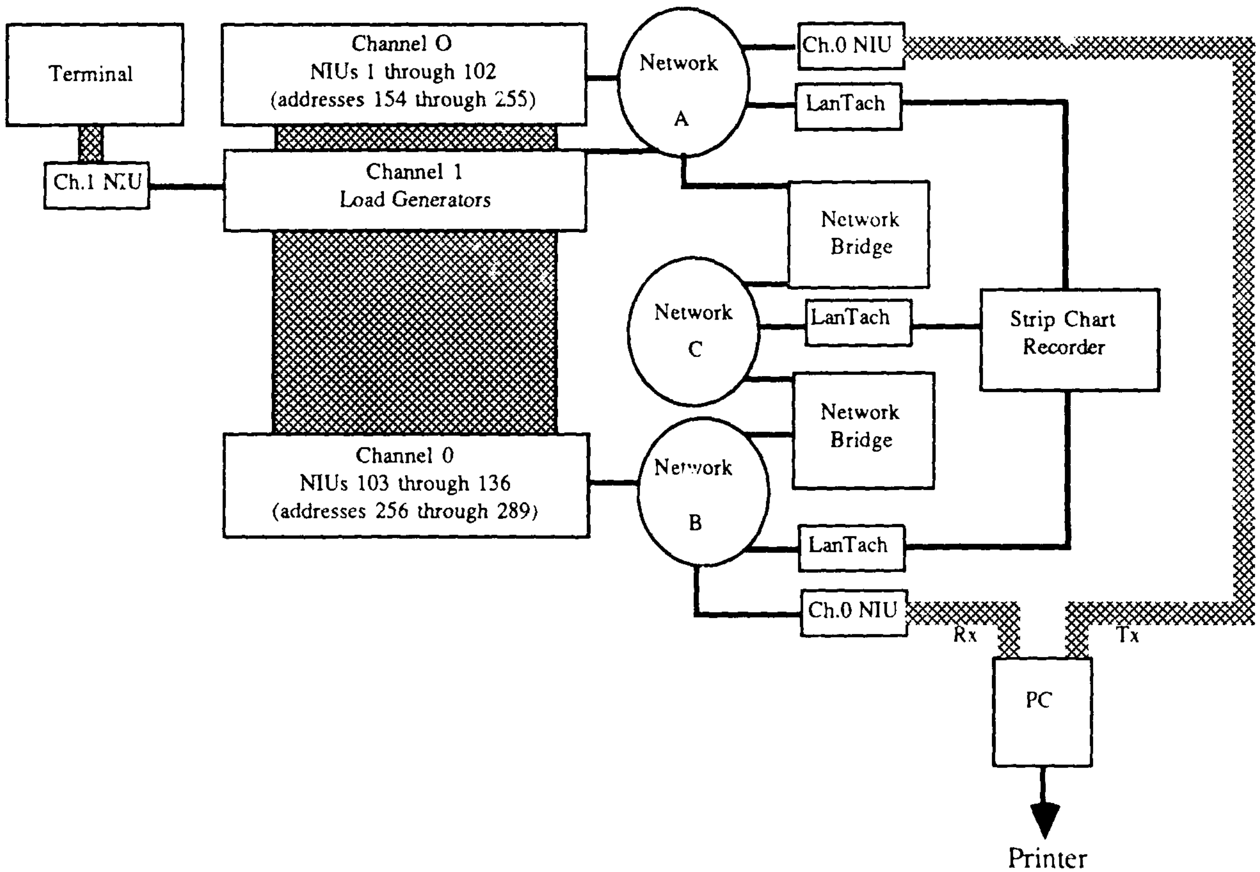


Figure 4-8. Cascaded Bridged Test Configuration

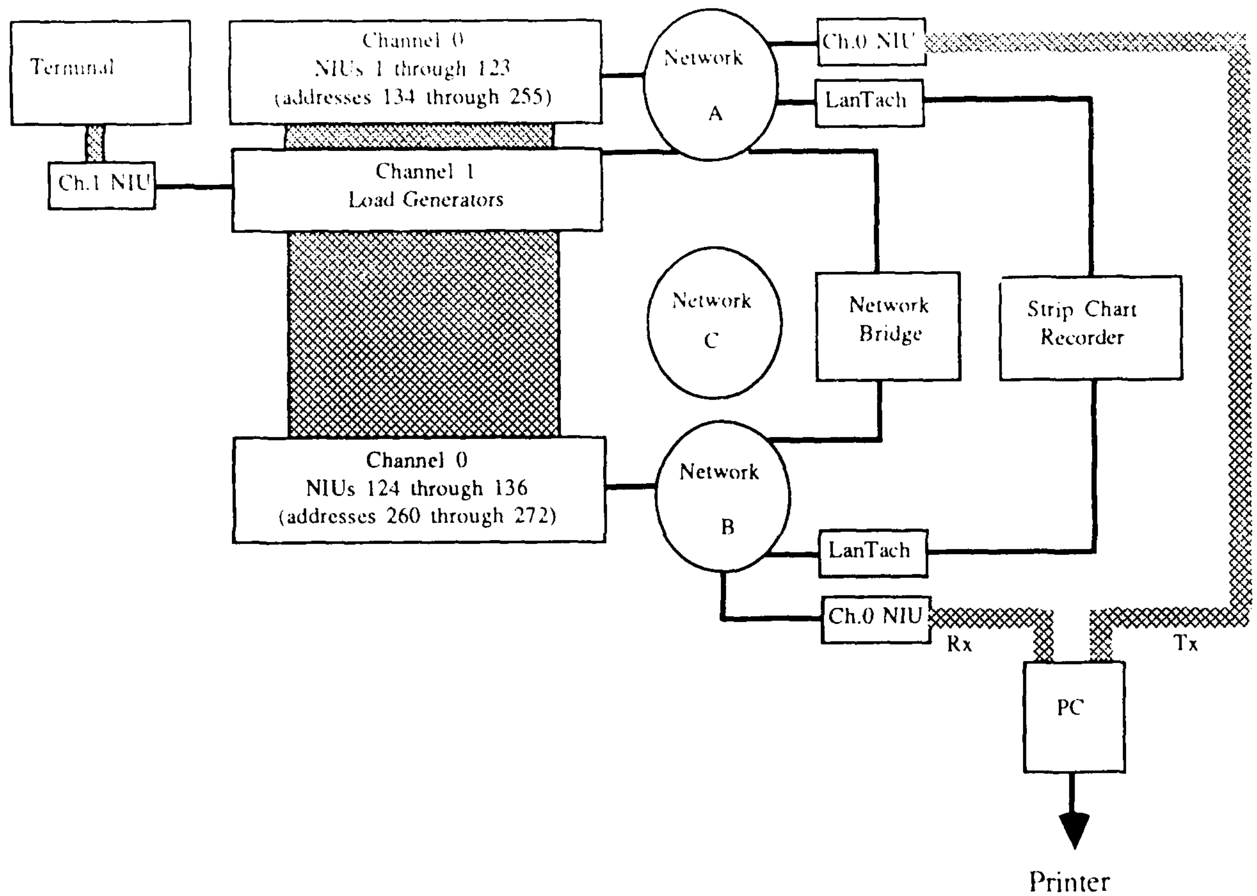


Figure 4-9. Altered Bridged Test Configuration (Used for Test 25 Only)

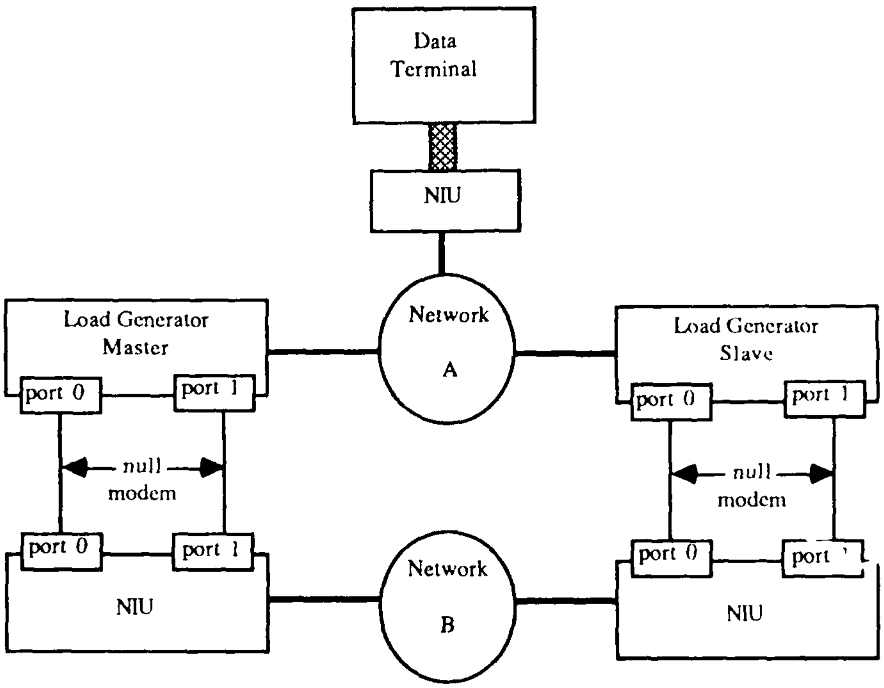


Figure 4-10. Load Generator Equipment Setup

CharRate defined the load generator transmission rate in characters per second. CharRate was limited by the baud rate and the data character parameters. If the specified CharRate exceeded the baud rate limitation, the resultant CharRate would be the highest possible given these restrictions. For example, given a character size of ten bits and a bit rate of 4800 bps, the maximum CharRate obtainable was 480 cps.

Cycle Time defined the time interval reserved for a given scenario transaction. A transaction was initiated by a master at the start of the cycle. If the transaction required less time than the Cycle Time reserved, then the load generator would be idle for the remainder of the cycle. The Cycle Time was greater than or equal to the time required for the transaction.

Table 4-2 describes the nine load generator scenario settings that were used in the network performance testing. These scenario settings correspond with the traffic type load characteristics described in section 3 of this document. Scenarios 0, 1, 2, and 3 correspond to the printer, Type 1, Type 2 and Type 3 terminal traffic types. Scenarios 4 and 5 are variations of the original Scenarios 1 and 3 (Type 1 and Type 3 terminal traffic types). Scenario 4 was jointly proposed by the test team. This modification of Scenario 1 decreased the cycle time thus doubling the offered load of the Type 1 terminal traffic type. Scenario 5 was proposed by MITRE. It is a modification of Scenario 3 and provided continuous echoplex traffic double that of the Type 3 terminal traffic offered in Scenario 3. Scenarios 6, 7, and 8 correspond with the word processing traffic types, data entry, screen refresh, and printer.

Table 4-2. Load Generator Settings

Scenario Number	Duty Cycle %	Burst Tx (characters)	Burst Rx (characters)	Echoplex (characters)	CharRate (char/sec.)	Cycle Time (seconds)
0	50	556	0	0	0	1
1	75	80	1920	80	0	120
2	75	80	1920	0	0	120
3	75	3	0	3	3	1
4	75	80	1920	80	0	60
5	75	6	0	6	6	1
6	50	5	0	5	0	1
7	25	3	1752	0	0	60
8	4	4380	0	0	0	5

4.2.2.2 End-to-End Test Tool

The delay test measurement tool is a software program developed for use on the IBM PC XT. The end-to-end delay test was used to measure the amount of time required for a single data character to be transmitted over the network. The delay is measured from the time a data character leaves the PC port through the transmit line of an RS-232 cable to an NIU port, to the time it arrives back through the receive line of an RS-232 cable to the PC port. Figure 4-11 shows a typical test configuration used for the end-to-end delay test. At least a full screen of characters (approximately 1000 one-character packets) was sent before halting the delay test. After the characters had been transmitted over the network, the delay program would provide the delay values (in milliseconds (msec)) for the minimum, 50 percent, 68.7 percent, 99.9 percent and maximum end-to-end delays.

4.2.2.3 LanTach

To measure the representative traffic load operating on a given network channel in real time, the TRW IND LanTach product was used. This device measures the ratio of carrier transmission time versus idle time with 100 percent representing continuous carrier present.

A four-channel strip chart recorder recorded the output of four LanTachs. Since the LanTach is quite sensitive to changes in traffic load, it was necessary to modify the output to obtain a smoother, more easily interpreted traffic load curve. Therefore, three of the four LanTachs were modified with a 400 microFarad capacitor so that the traffic load could be integrated over a brief period with an instantaneous average measured. The fourth LanTach measured the real-time traffic load. By recording both, the measured real-time traffic load could be compared (if necessary) with the measured average traffic load.

4.2.3 Test Composition

Twenty-six tests evaluated the network channel load and end-to-end delays experienced on the network. Table 4-3 lists the performance tests and their composition. The table is divided into four parts: test number, test configuration type, parameter settings, and percent load generator scenario traffic (local and bridged).

Eighteen tests were associated with pure traffic transaction types. Each traffic transaction type was tested in each of the three network configurations. In the unbridged tests, 100 percent of a specific traffic transaction type or scenario was used. In the bridged and cascaded bridged tests, 75 percent of the specified traffic transaction type was local (not bridged) and 25 percent of the traffic was bridged.

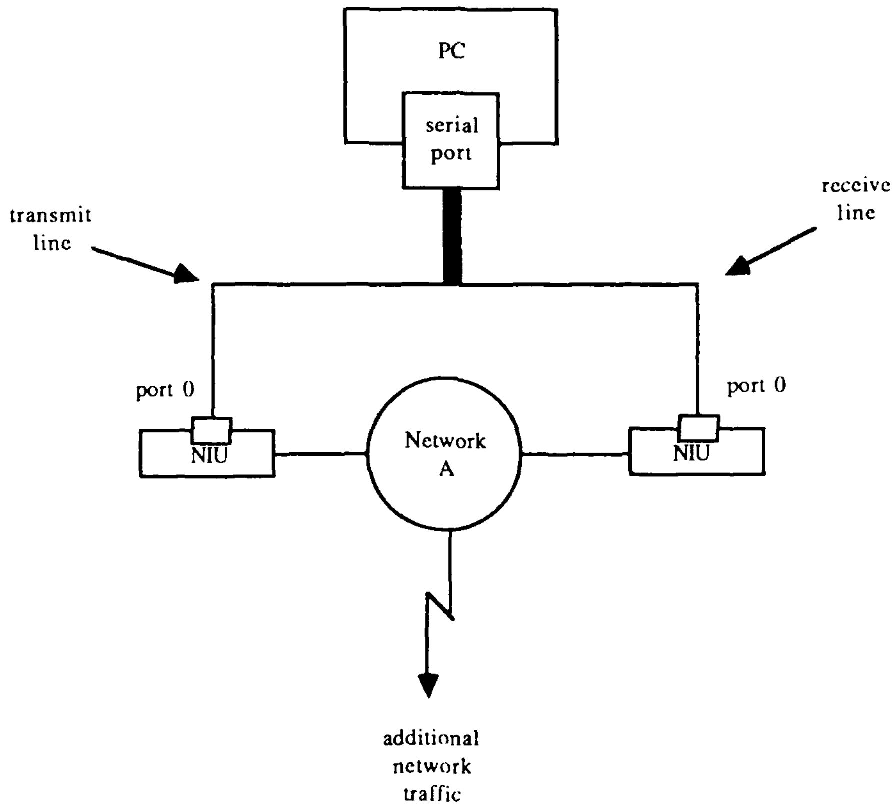


Figure 4-11. Delay Measurement Test Configuration

Table 4-3. Test Composition of Performance Tests

Test Number	Test Configuration	Parameter Settings: NIU Buftime	NIU Acklatency	Network Bridge Ack Reserve	Percent Load Generator Scenario Traffic: Local 0	Local 1	Local 2	Local 3	Local 4	Local 5	Local 6	Local 7	Local 8	Bridged 0	Bridged 1	Bridged 2	Bridged 3	Bridged 4	Bridged 5
1	Unbridged	3	17		100.00														
2	Unbridged	3	17			100.00													
3	Unbridged	3	17				100.00												
4	Unbridged	3	17					100.00											
5	Unbridged	3	17		16.70	20.80	41.70	20.80											
6	Bridged	3	17	170	75.00									25.00					
7	Bridged	3	17	170		75.00									25.00				
8	Bridged	3	17	170			75.00									25.00			
9	Bridged	3	17	170				75.00									25.00		
10	Bridged	3	17	170	12.53	15.60	31.28	15.60						4.18	5.20	10.42	5.20		
11	Cascaded	3	17	170	75.00									25.00					
12	Cascaded	3	17	170		75.00									25.00				
13	Cascaded	3	17	170			75.00									25.00			
14	Cascaded	3	17	170				75.00									25.00		
15	Cascaded	3	17	170	12.53	15.60	31.28	15.60						4.18	5.20	10.42	5.20		
16	Unbridged	3	17			25.00	50.00	25.00											
17	Unbridged	3	17						100.00										
18	Bridged	3	17	170		18.75	37.5	18.75						6.25	12.50	6.25			
19	Bridged	3	17	170					75.00									25.00	
20	Cascaded	3	17	170		18.75	37.5	18.75						6.25	12.50	6.25			
21	Cascaded	3	17	170					75.00									25.00	
22	Unbridged	3	17							100.00									
23	Bridged	3	17	170						75.00									25.00
24	Cascaded	3	17	170						75.00									25.00
25	Bridged	3	17	170	16.25	16.25	32.5	16.25						3.75	3.75	7.50	3.75		
26	Unbridged	3	17								80.00	10.00	10.00						

Notes:
Buftime = [10*(2+setting)]msec
Acklatency = [10*setting]msec
AckReserve = [setting]msec

Eight tests were associated with proportional mixes of the traffic transaction types. The proportions of the traffic transaction type or scenario varied. Three tests were performed using the proportional mix defined for the expected traffic on the ALC LANs. This mix was as follows:

Scenario	Proportion
0	16.7%
1	20.8%
2	41.7%
3	20.8%

These proportions were used for the unbridged network configuration. For the bridged network configurations, the ratio of local (not bridged) to bridged was 75:25. Therefore, traffic proportions for tests that required either type of bridged traffic were as follows:

Scenario	Proportion
local 0	12.5%
local 1	15.6%
local 2	31.3%
local 3	15.6%
bridged 0	.2%
bridged 1	5.2%
bridged 2	10.4%
bridged 3	5.2%

Three other tests evaluated the channel load and delay associated with a combination of only the terminal traffic transaction types (Scenarios 1, 2, and 3) using the three network configurations. These tests determined the impact of printer traffic on channel loading. The ALC LAN expected proportional mix determined the proportion of scenarios 1, 2, and 3; the proportion of local to bridged traffic was 75:25.

One test evaluated the channel load of Scenarios 0, 1, 2, and 3 with a proportion of local to bridged traffic of (81.25):(18.75). These tests determined the impact of the proportion of local to bridged traffic on channel loading and delay.

The last of the 26 tests evaluated the channel load of the word processing Scenarios 6, 7, and 8.

4.2.4 Approach

The network(s) were initially loaded with traffic of a single transaction type to establish the relative loading capability of each type. In subsequent tests, proportional mixes of these types were used to simulate actual network conditions.

For each test, the number of virtual circuit transactions was increased in increments of 9 to 15 virtual circuits. Whenever possible, automated scripts, run on a Macintosh personal computer, were used to establish the virtual circuits and initiate the load generator traffic transmissions. An end-to-end delay test was performed at each additional increment of virtual circuits.

4.3 SENSITIVITY EVALUATION

These tests provided insight into the flexibility of the NIU and its adaptability to various traffic load characteristics. Since most of the NIU parameters are settable in the firmware, these tests focused on changing specific NIU parameter settings to determine whether NIU parameter tuning could make a difference in the operation of large, heavily loaded networks. The parameters were those that could change the size of the packets sent over the network and the protocol timing.

4.3.1 Objectives

Three parameters were evaluated for sensitivity to network load and end-to-end delay, namely, Buftime, Acklatency, and Ack reserve. The performance of the default settings of these parameters was compared with settings modified for the particular traffic of interest. The traffic of interest was determined after completion of the network load and end-to-end delay testing. In this way it could be determined if it was necessary to reduce the network loading for specific traffic transaction types and achieve better performance (as determined with the loading and end-to-end delays) through changes in NIU parameters.

The Buftime parameter sets the packet assembly time. 'Buftime' controls the amount of possible data that can fit into a packet. When the first character comes in from the user device and is placed in an empty buffer, a timer is initialized. Every ten msec, it is decremented. When the counter reaches zero, the packet is ready to be transmitted. All incoming characters are added to the packet, unless the buffer size (256 bytes) is exceeded. If the maximum buffer size is reached before the timer goes off, the packet is automatically transmitted. By modifying this parameter, one can better match the size of the data packet to the types of traffic generated and optimize performance. The default setting for Buftime is 3 (50 msec).

The Acklatency parameter controls the amount of time between transmission of a data packet and its acknowledgement packet. During this time only the receiving NIU is allowed to transmit. This parameter is critical to the operation of the NIU's CSMA with priority acknowledgement protocol. All senders of data packets avoid conflict with the acknowledgement traffic because they wait for the 'Acklatency' period before transmitting another data packet. In essence, the Acklatency parameter reserves a time slot for the acknowledgement packet to be transmitted in a priority manner across the network. The value of this parameter is set to accommodate the expected propagation delay on the network. By modifying this parameter to correspond with the network propagation delay, the channel time available for data transmission can be maximized. The default setting for Acklatency is 17 (170 msec).

The Ack reserve parameter of the bridge initiates a hold on the source channel after a data packet has passed through the bridge to enable the acknowledgement to pass through the bridge back to the source NIU without colliding with another packet. The Ack reserve parameter sets the amount of time allowed for an acknowledgement packet to return through the bridge after it is transmitted. Like the Acklatency parameter, this parameter would be set to accommodate the expected propagation delay on the network. It should be set to be less than or equal to the Acklatency parameter setting. By properly setting this parameter, the source channel 'hold' time is minimized thus maximizing the potential data traffic. The default setting for Ack reserve is 170 (170 msec).

4.3.2 Test Configuration

This testing, like the network load evaluation and end-to-end delay testing, used unbridged and bridged network configurations in the testbed. The load generators, end-to-end delay test tool, and the LanTach were also used (see 4.2.2).

4.3.3 Test Composition

There were a total of eleven tests conducted to determine parameter sensitivity. Table 4-4 lists the composition and NIU test parameters for the sensitivity tests. This table is divided into four parts: test number, test configuration type, parameter settings, and percent load generator scenario traffic (local and bridged).

Six of the tests were performed in the unbridged test configuration. One of the six tests modified the buftime parameter setting to allow a larger packet size for the printer traffic. The other tests modified the Acklatency parameter setting to allow less time between the data packet and its acknowledgement packet.

The remaining five tests were performed in the bridged test configuration. These tests modified the Ack reserve parameter setting of the bridge, to allow less time for the bridge to hold the source channel for the acknowledgement to pass back through the bridge without collision, and the Acklatency parameter setting, to allow less time between the data packet and its acknowledgement on the destination channel.

4.3.4 Approach

The tests followed the same steps stated in the approach for the load evaluation and end-to-end delay test. The specific NIU parameter under test was set prior to the start of testing.

Table 4-4. Test Composition of Sensitivity Tests

Test	Test	Parameter Settings			Percent Load Generator Scenario Traffic														
		NIU	NIU	Network Bridge	Local	Local	Local	Local	Local	Local	Local	Local	Local	Bridged	Bridged	Bridged	Bridged	Bridged	Bridged
Number	Configuration	Buftime	Acklatency	Ack Reserve	0	1	2	3	4	5	6	7	8	0	1	2	3	4	5
27	Unbridged	27	17		100.00														
28	Unbridged	3	13		100.00														
29	Unbridged	3	13			100.00													
30	Unbridged	3	13				100.00												
31	Unbridged	3	13					100.00											
32	Unbridged	3	13		16.70	20.80	41.70	20.80											
33	Bridged	3	13	76	75.00									25.00					
34	Bridged	3	13	76		75.00									25.00				
35	Bridged	3	13	76			75.00									25.00			
36	Bridged	3	13	76				75.00									25.00		
37	Bridged	3	13	76	12.53	15.60	31.[illegible]	15.60						4.1[illegible]	5.20	10.42	5.20		

Notes:
Buftime = [10*(2+setting)]msec
Acklatency = [10*setting]msec
AckReserve = [setting]msec

SECTION 5

RESULTS

This section describes the results of the three phases of performance testing.

5.1 PROTOCOL CHARACTERIZATION

The protocol characterization tests focused on the part of the NIU protocol related to data transfers across an established virtual circuit. Thus, the data packet and priority acknowledgement portions of the protocol were highlighted. Not covered during the testing was a characterization of the datagram messages. Datagram messages are typically used to query the network or respond to queries from the network especially during the virtual circuit establishment process; datagram messages do not require acknowledgement.

5.1.1 Packet Structure

The fundamental element of the NIU protocol is the packet frame. The data is framed by leading and trailing flags. The protocol is based on an exchange of packets which encapsulate the higher level information required for reliable information transfer. All packets are constructed from the following basic pieces:

a) carrier-on;

b) leading flags of variable length;

c) header field of 18 bytes including two byte destination address, two byte packet version number, two byte packet length, one byte packet type, eight byte control field, one byte sequence number, and two byte source address;

d) information field of 0 to 256 bytes of data (or datagram message information);

e) cyclical redundancy check (CRC) of two bytes based on the CCITT CRC-16 algorithm;

f) trailing flags of variable length;

g) carrier-off.

Upon initiation of a transmission (with no carrier detected on the cable), the RF modem will begin with 16 bit times of solid carrier to allow the automatic gain control (AGC) circuitry of the receivers to adjust the reception gain. At the conclusion of a transmission, the RF modem will shut down within 16 bit times (also called carrier-off). Figure 5-1 shows the elements of a typical data packet and acknowledgement packet.

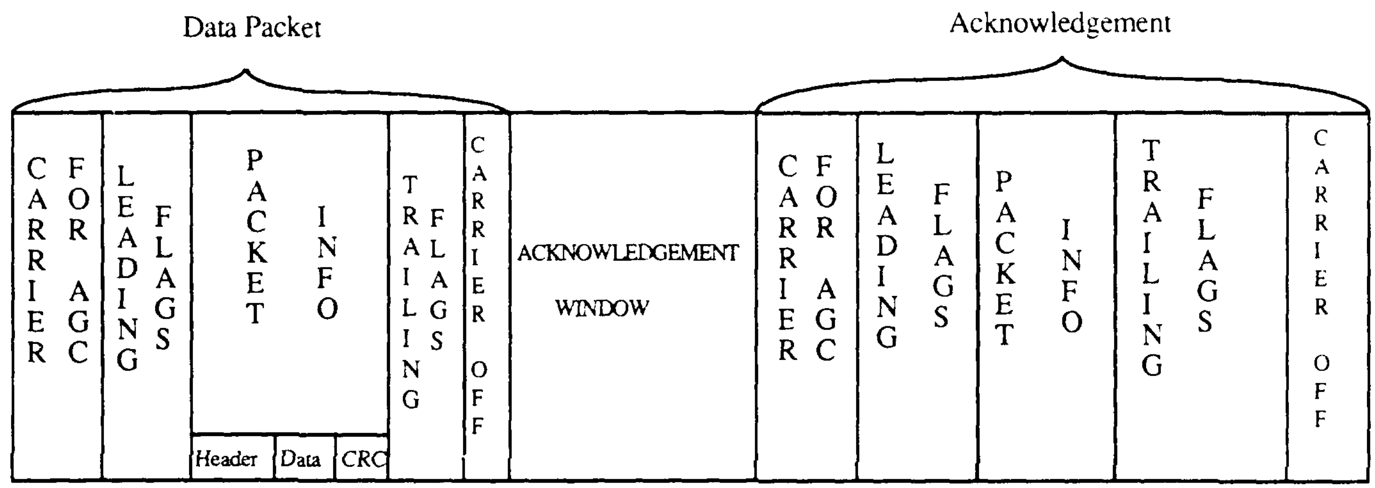


Figure 5-1. Packet Structure (not to scale)

5.1.2 Packet Timing

At a transmission rate of two Mbps, a bit time is 0.5 microseconds (μs). Therefore, the best case packet transmission time is as follows:

Best Case = Packet size (bytes) x 4 μs per byte

During packet transmission and in accordance with the NRZI zero insertion scheme, a zero bit is inserted between a packet's leading and trailing flags after a transmission series of five consecutive one bits in a row; this allows for special sequences of consecutive one bits to be defined for flags, aborts, and idle lines. The best case packet would have no series of five consecutive one bits in a row and the worst case would have a packet of all one bits. Due to the uncertainty related to the additional bits added to the data stream, the actual packet transmission duration can vary as much as 16.7 percent above the best case. Therefore, the worst case packet time is as follows:

Worst Case = Best Case + (Best Case x 16.7%)

The consequences of these variations can be seen in the packet timing results.

Table 5-1 presents the results of the packet information measurements for the three test configurations.

5.1.3 Summary

Protocol overhead introduced by all functional control layers between the source and destination is large. For each packet with 1 to 256 data characters, there is 176 μs to 195 μs of non-information overhead. The non-information overhead includes the AGC burst, leading flags, header, CRC, trailing flags, and carrier turn-off. When the acknowledegment packet is added into the total time for packet transmission, another 464 μs to 487 μs is added; the acknowledgement packet contains the same overhead components as the data packet. Without any propagation delay, the acknowledgement window adds another 111 μs to 120 μs to the total time to transmit a single packet and receive a response. This translates into approximately 99.5 percent overhead for a 'best case' one character (of data) packet and approximately 99.4 percent overhead for a 'worst case' one character (of data) packet. Using a 256 character packet, there is a 43 percent improvement: 'best case' 256 character packet has approximately 42.3 percent overhead and a 'worst case' 256 character packet has approximately 40.2 percent overhead.

Table 5-1. Protocol Characterization Packet Timing Summary

Packet Information	Configuration A Characters per Packet				Configuration B Characters per Packet				Configuration C Characters per Packet			
	1	96	192	256	1	96	192	256	1	96	192	256
Data Packet and Acknowledgement	800.0			1860.0	857.0			1680.0	780.0			1680.0
Data Packet	195.6	476.0	863.0	1160.0	195.6	650.0	1030.0	1280.0	180.0	580.0	950.0	1184.0
Data Packet AGC Burst	11.6			12.0	9.6			9.8	8.9			9.8
Data Packet Leading Flags	32.1			32.1	32.1			32.0	11.5			11.5
Data Packet Information	95.4			1074.0	95.0			1080.0	97.0			1140.0
Data Packet Trailing Flags	48.0			48.0	48.0			48.1	48.7			44.3
Data Packet Carrier Turn-off	9.0			9.5	10.0			9.0	13.5			13.7
Acknowledgement Window	119.2			111.2	50.0			50.5	111.6			112.2
Acknowledgement Packet AGC Burst	10.0			10.4	8.4			8.5	9.2			9.2
Ack Reserve(Configuration C Only)	N/A			N/A	N/A			N/A	330.0			341.5
Acknowledgement Packet Leading Flags	193.0			188.4	23.6			23.6	188.6			188.0
Acknowledgement Packet Information	94.6			95.0	98.5			98.5	98.5			92.4
Acknowledgement Packet Trailing Flags	184.0			180.0	160.0			180.6	179.0			176.2
Acknowledgement Packet Carrier Turn-off	8.0			9.0	14.0			14.0	9.0			11.8

Note: All values in microseconds

5.2 LOAD AND DELAY SUMMARY

The load and delay tests focused on the measurement of the channel loads and resultant delays caused by the addition of the traffic transaction types presented in section 3. Since the propagation delay and carrier noise level affects were less of a concern, the traffic load and end-to-end delays were measured in the absence of either of these factors. Table 5-2 presents a summary of the results of the load and end-to-end delay tests (Tests 1-26). The table is divided into five parts: test number, test configuration, the number of virtual circuits remaining after the last end-to-end delay test measurement was taken, resultant bus load, and one-way end-to-end delay time. The appendix presents more detailed results on each test's end-to-end delay tables, bus load vs. background traffic charts, and end-to-end delay vs. bus load charts for each incremental virtual circuit.

5.2.1 Test Comparisons

Although the load and delay tests could be compared in a number of different groupings, for our purposes the tests have been divided into three groups.

The first group includes the pure traffic types: printer traffic (Test 1), Type 1 traffic (Test 2), Type 2 traffic (Test 3), Type 3 traffic (Test 4), Type 1 traffic doubled (Test 17), Type 3 traffic doubled (Test 22). These tests show that the printer traffic generated the highest load; 40 percent of the time carrier was detected on the network. The Type 3 (echoplex) traffic also generated high loads; 32 percent of the time carrier was detected on the network in Test 4 and 36 percent of the time in Test 22. Type 1 and 2 traffic presented the lowest loads with all tests showing carrier on 10 percent of the time or less.

The end-to-end delays for the first group show the printer and Type 3 traffic exhibiting the greatest mean delays; around 100 msec with loads approaching 40 percent carrier on. Type 1 and 2 traffic exhibited relatively low mean delays on the order of 20 msec.

The second group includes the different mixes of traffic types: printer, Type 1, Type 2, and Type 3 traffic unbridged and bridged (Tests 5 and 10); Type 1, Type 2, and Type 3 traffic unbridged and bridged (Tests 16 and 18); and the word processor traffic unbridged (Test 26). These tests show that bridging reduced the overall network load by 1 to 2 percent, presumably by distributing the load between the local and bridged networks. By removing the printer traffic from the network, the load was reduced significantly. Tests 5 and 10, which included the printer traffic exhibited maximum loads on the order of 24 percent. Tests 16 and 18 which excluded the printer traffic, exhibited maximum loads on the order of 14 percent. The word processing traffic (including printer traffic) in Test 26 showed a maximum load of 30 percent, slightly higher than the other mixes of traffic types.

The end-to-end delays for the second group show increasing delays with increasing loads. The word processing traffic that exhibited the highest load also exhibited the highest mean delay, 81 msec. The traffic with the next highest load, the printer and three terminal traffic types, had delays around 40 msec. The traffic with the lowest load, the three terminal traffic types without the printer traffic, had delays around 25 msec.

Table 5-2. Summary of Network Load and End-to-End Delay Results

Test Number	Test Configuration	Number of Virtual Curcuits	Resultant Bus Load (%) Network A	Network B	Network C	One-Way End-to-end Delay Time (msec) Minimum	50.00%	68.70%	Mean	99.90%	Maximum
1	Unbridged	111	40.0			10	35	66	128	2654	2924
2	Unbridged	134	8.0			10	15	17	20	176	1914
3	Unbridged	134	4.0			10	15	16	16	67	87
4	Unbridged	123	32.0			10	36	68	104	2571	2727
5	Unbridged	136	24.0			10	16	18	38	1271	1604
6	Bridged	105	41.0		12.0	10	35	65	110	3390	4008
7	Bridged	136	6.0		5.0	10	15	16	17	128	240
8	Bridged	136	5.0		2.0	10	15	16	18	146	223
9	Bridged	131	33.0		11.0	10	33	64	129	2644	3871
10	Bridged	134	22.0		6.0	10	15	34	43	1169	1219
11	Cascaded	100	38.0	2.0	1.5	10	33	63	127	2891	4093
12	Cascaded	130	5.5	2.5	2.5	10	13	14	16	99	171
13	Cascaded	136	6.0	3.0	3.0	10	14	14	17	90	136
14	Cascaded	122	32.5	8.0	8.0	10	31	63	109	2068	2601
15	Cascaded	136	20.5	4.5	4.5	10	15	31	37	627	928
16	Unbridged	136	14.0			10	14	17	25	240	498
17	Unbridged	136	10.0			10	14	15	20	225	307
18	Bridged	134	15.5		5.0	10	14	17	27	321	510
19	Bridged	135	11.0		4.5	10	14	16	20	147	220
20	Cascaded	134	15.0	6.0	6.0	10	14	18	29	401	1013
21	Cascaded	127	9.0	3.0	3.0	10	14	15	21	223	466
22	Unbridged	95	36.0			10	35	65	115	2356	3697
23	Bridged	107	36.0		12.0	10	34	65	127	3406	3881
24	Cascaded	92	34.0	5.0	5.0	10	36	66	125	2611	3169
25	Bridged	126	22.5		4.0	10	16	33	38	987	1076
26	Unbridged	128	30.0			10	17	53	81	2001	3241
27	Unbridged	136	28.0			10	15	32	43	1344	1415
28	Unbridged	126	41.5			10	42	80	142	2614	3024
29	Unbridged	135	5.8			10	13	14	17	82	114
30	Unbridged	136	5.8			10	13	14	17	137	142
31	Unbridged	135	34.5			10	35	63	113	3238	3238
32	Unbridged	134	20.5			10	14	19	39	1054	1159
33	Bridged	119	40.0		10.5	10	43	86	171	3438	3734
34	Bridged	133	6.0		3.0	10	13	14	17	106	340
35	Bridged	136	4.8		2.8	10	13	14	16	105	126
36	Bridged	135	32.5		9.5	10	34	64	118	2893	4057
37	Bridged	134	21.0		6.5	10	15	33	41	909	962

The third group includes the two proportional mixes of bridged traffic types (Tests 10 and 25). These two tests show that the load and delay remained constant even when the proportion of local to bridged traffic changed.

5.2.2 Summary

It is clear from the traffic load curves that the percentage of loading, as a measure of carrier on time, leveled off at around 40 percent. Although 136 virtual circuits were established during each test, in a number of cases, some were dropped (after 20 attempts to transmit the NIU was designed to disconnect the virtual circuit) due to very high traffic loads on the network. This is especially apparent in the tests using the printer and echoplex traffic.

The end-to-end delay clearly increased as the traffic load increased. The end-to-end delay test results show that a very large percentage of traffic, on the order of 75 percent, experience delays under the mean delay. Fifty percent of the traffic experienced delays on the order of under 40 msec even at the maximum load of 40 percent carrier on time.

5.3 SENSITIVITY

The sensitivity tests focused on the measurement of the channel loads and delays resulting from changes in specific NIU parameters. Table 5-2 presents a summary of the results of the sensitivity tests (Tests 27-37). The table is divided into five parts: test number, test configuration, the number of virtual circuits remaining after the last end-to-end delay test measurement was taken, resultant bus load, and one-way end-to-end delay time (table 4-5 lists the specific parameter setting for the sensitivity tests). The appendix presents more detailed results on each test's end-to-end delay tables, bus load vs. background traffic charts, and end-to-end delay vs. bus load charts for each incremental virtual circuit.

5.3.1 Test Comparison

Although the sensitivity tests could be compared in a number of different groupings, for our purposes the tests have been divided into three groups.

The first group contains the pure traffic types: printer traffic (Tests 1, 27 and 28), Type 1 traffic (Tests 2 and 29), Type 2 traffic (Tests 3 and 30), Type 3 traffic (Tests 4 and 31). These tests show that increases in the Buftime parameter reduced the network load and resultant end-to-end delays and decreases in the Acklatency parameter affected little change in the network load or end-to-end delays. When Buftime was reset to allow larger sized packets, the maximum load was reduced from a load of 40 percent carrier on time (Tests 1 and 28) to a load of 28 percent carrier on time (Test 27); end-to-end delays for Test 27 decreased to a mean of 43 msec, well below the mean delays experienced in Tests 1 or 28 of 128 and 142 msec, respectively. Changing the Acklatency parameter to reflect the small propagation delay in the test configuration did not seem to affect the network load or end-to-end delay.

The second group includes the different mixes of traffic types, printer, Type 1, Type 2, and Type 3 traffic, operating on an unbridged network (Tests 5 and 32). These tests show that by changing the Acklatency parameter, the load could be reduced some (from 24 percent to 20 percent) by decreasing the amount of time the NIU waited for the channel to be free. However, there was no real corresponding reduction in the end-to-end delays.

The third group includes the different mixes of traffic types, printer, Type 1, Type 2, and Type 3 traffic, operating on a bridged network (Tests 10 and 37). These two tests show that the load and delay remained constant even when the Acklatency and Ack reserve parameters were changed to reflect the small propagation delay in the test configuration.

5.3.2 Summary

By changing certain NIU parameter default values to reflect the traffic characteristics and LAN characteristics (e.g., propagation delay), performance, as measured by the traffic load and end-to-end delay, does improve. The most significant change in network load (and delay) occurred when the buftime parameter was changed to allow larger data packet sizes for the printer traffic scenarios. Changes in the Acklatency default parameter (and Ack reserve default parameter in networks that are bridged) to reflect the propagation delay may contribute to reductions in load or end-to-end delay only when there is a great degree of mismatch between the default parameter value and the true network delay.

SECTION 6

SUMMARY AND CONCLUSIONS

This paper has provided a description of the ALC LAN system performance test performed by the test team of TRW IND, TRW SEDD, and MITRE. These system performance tests confirmed that the assumptions used in earlier analytical models were appropriate, and although the model did not adequately characterize the statistical performance of individual network channels based on the traffic described in the system specification, the model results were comparable to the results of these tests.

The echoplex and word processing traffic stressed the performance of this network protocol substantially. Most surprising was the stress caused by the printer traffic scenarios. This traffic type stressed the protocol performance the most. The ALC LANs network managers should consider placing the printer traffic on separate channels because this traffic type affects the delays for all non-printer applications. Users are less concerned about the end-to-end delay associated with obtaining a printed copy of a file than about the end-to-end delay associated with an interactive session with a host.

Fine tuning of certain NIU parameters could provide the users with better performance. The NIU tuning should be approached with care since the environment of the ALCs is often unstable due to frequent personnel moves. Tuning for one configuration may not be appropriate for another.

For purposes of channel allocation and planning, one must look at the number of host ports on a particular channel rather than the number of non-host ports. Traffic characteristics, especially echoplex traffic types, play a significant role in the network using the CSMA priority acknowledgement protocol. This should be taken into consideration when procuring new or modifying old LMS. AFLC should promote procuring systems based on modern workstations that provide file-by-file interactions (host downloads a file to workstation, transactions performed locally, workstation uploads file to host). It is anticipated that with the proliferation of modern workstations on the network, the network channel load and the network contribution (excluding the host processing) to the end-to-end delay will be reduced.

The information gained from this testing should be expanded as the systems are fully implemented and better traffic definitions are known. In addition, the technical control and monitoring (TCM) system should provide insight into the utilization of the networks and should be relied upon when fine-tuning the NIU parameters. If high network traffic loads exist, Network Managers may want to limit the percent carrier-on time on specific network channels to avoid the shedding of links due to very high traffic loads on the network; additional channels could be used to handle the off-loaded traffic.

BIBLIOGRAPHY

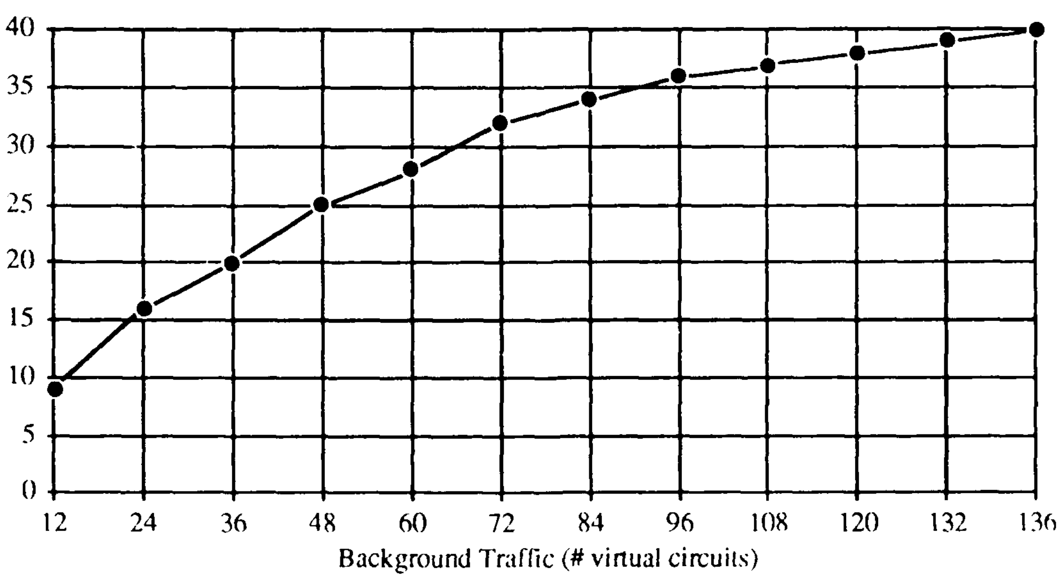
Specification No. OCL-3104C-10002C, FSCM 50464, "System Specification for the Air Force Logistics Command Air Logistics Centers Local Area Networks," 4 January 1988.

APPENDIX

PERFORMANCE TEST RESULTS

Test 1

Background Traffic (vc's)	Bus Load (%)	Mean Delay (msec)	Min. Delay (msec)	<=50% Delay (msec)	<=68.7% Delay (msec)	<=99.9% Delay (msec)	Max. Delay (msec)	Total Characters Transferred
12	9	19	10	15	17	98	295	1003
24	16	27	10	15	16	471	1178	1005
36	20	30	10	16	17	700	711	1003
48	25	46	11	17	36	981	1115	1003
60	28	49	10	17	43	1040	1095	1003
72	32	67	10	17	54	1870	2611	1001
84	34	90	10	33	57	2374	2383	1001
96	36	102	11	31	63	2333	2460	1005
108	37	98	11	19	57	1800	2237	1004
120	38	109	10	34	65	2965	3407	1003
132	39	128	10	36	68	2468	2610	1002
136	40	128	10	35	66	2654	2924	1004



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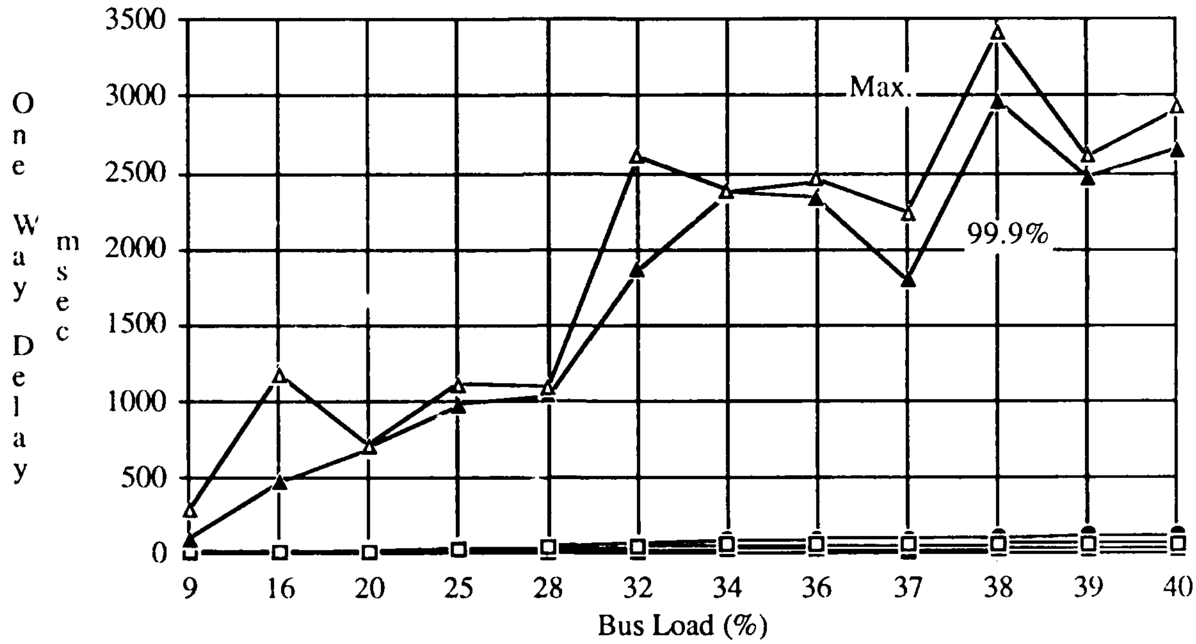
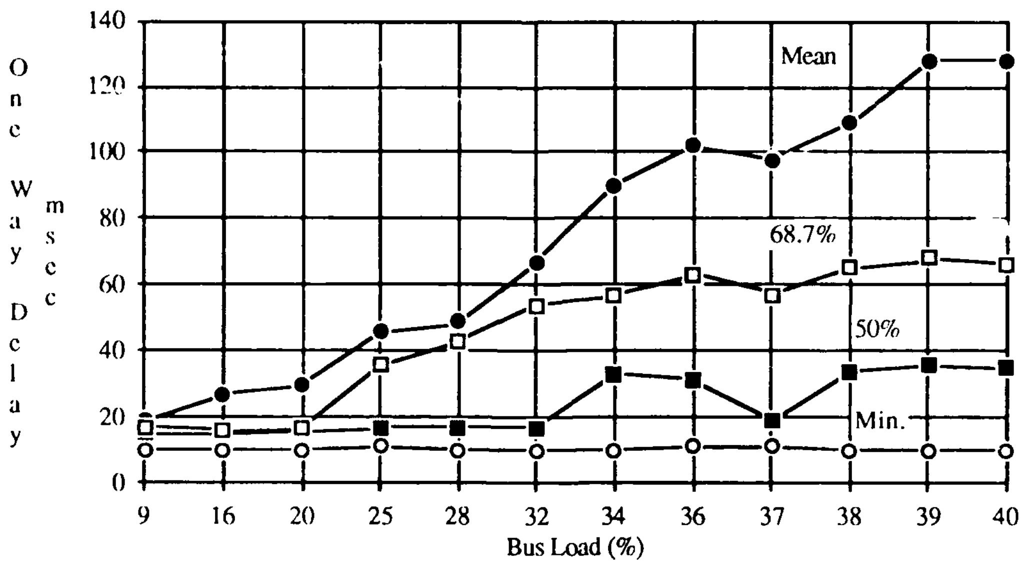
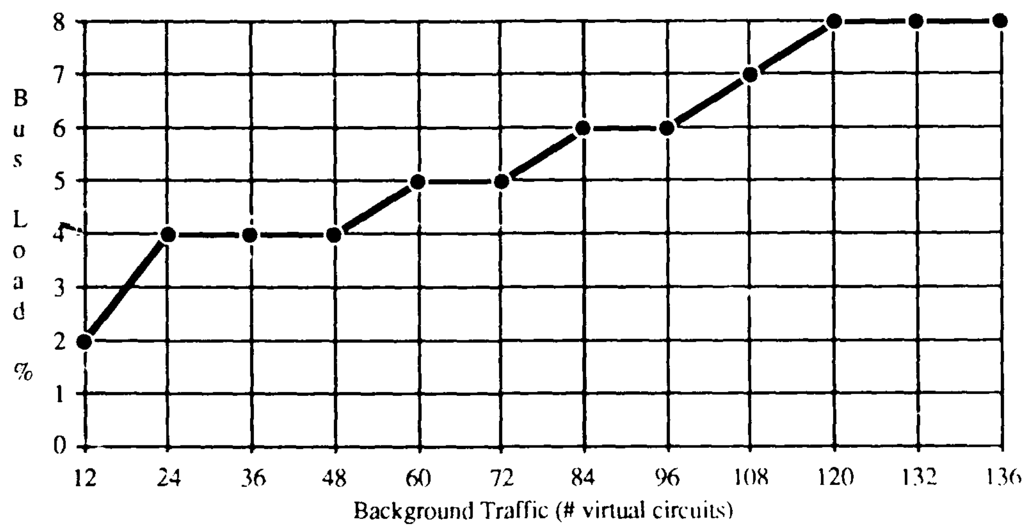




Test 2

Background Traffic (vc's)	Bus Load (%)	Mean Delay (msec)	Min. Delay (msec)	<=50% Delay (msec)	<=68.7% Delay (msec)	<=99.9% Delay (msec)	Max. Delay (msec)	Total Characters Transferred
12	2	14	10	13	14	56	65	1001
24	4	16	10	15	16	67	67	1000
36	4	17	10	15	16	101	148	1000
48	4	16	10	15	16	119	261	1000
60	5	16	10	15	16	65	66	1000
72	5	16	10	15	16	66	69	999
84	6	15	10	13	15	68	83	1000
96	6	18	10	15	17	160	190	1001
108	7	19	10	15	17	149	469	1000
120	8	16	10	15	15	68	69	1000
132	8	19	10	15	17	213	233	1000
136	8	20	10	15	17	176	1914	1000



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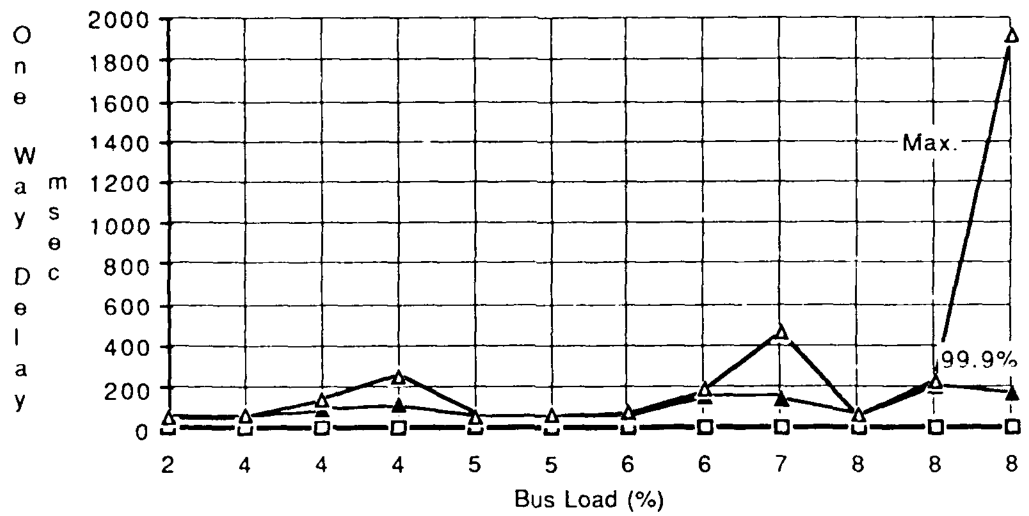

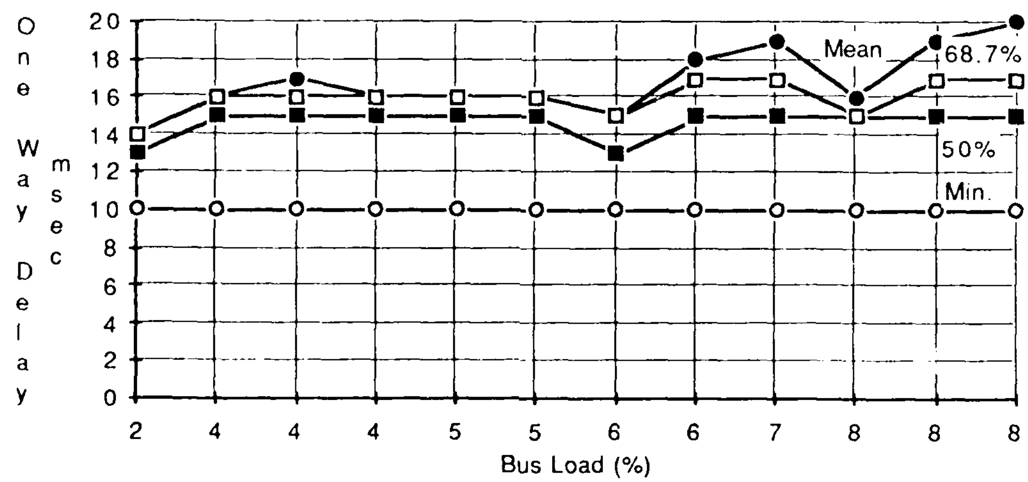

Test 3

Background Traffic (vc's)	Bus Load (%)	Mean Delay (msec)	Min. Delay (msec)	<=50% Delay (msec)	<=68.7% Delay (msec)	<=99.9% Delay (msec)	Max. Delay (msec)	Total Characters Transferred
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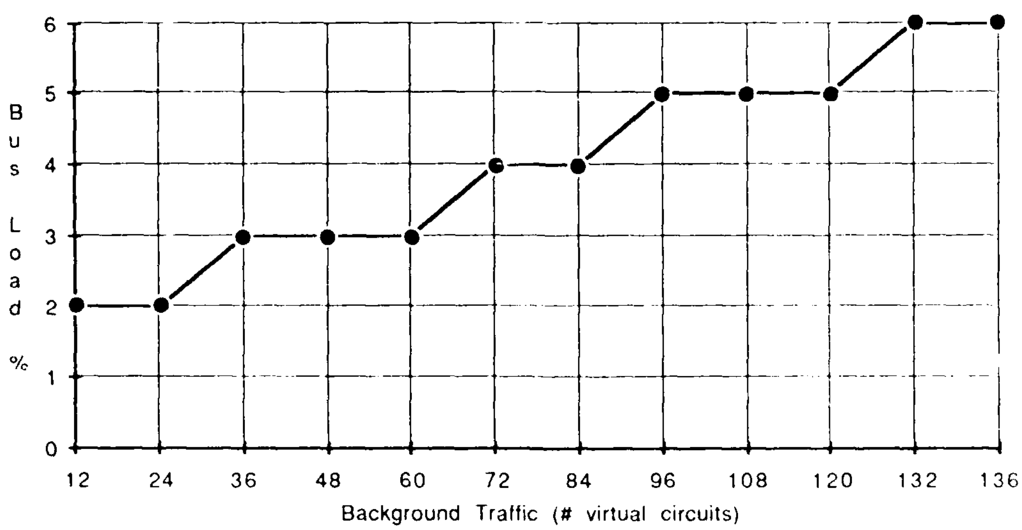
24	2	16	10	15	16	63	66	1001
36	3	16	10	15	16	67	140	996
48	3	14	10	13	14	62	114	1002
60	3	16	10	15	16	67	67	1000
72	4	16	10	15	16	66	178	1001
84	4	16	10	15	16	67	87	1003
96	5	17	10	15	16	125	125	1003
108	5	17	10	15	16	69	76	1004
120	5	17	10	15	16	83	148	1002
132	6	18	10	15	17	108	114	1004
136	6	19	10	15	17	284	439	1002



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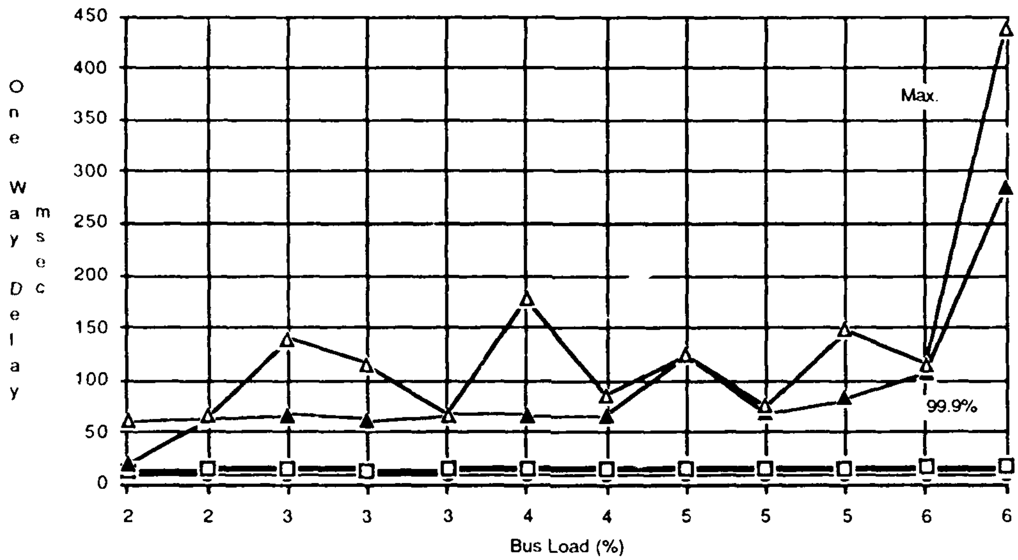
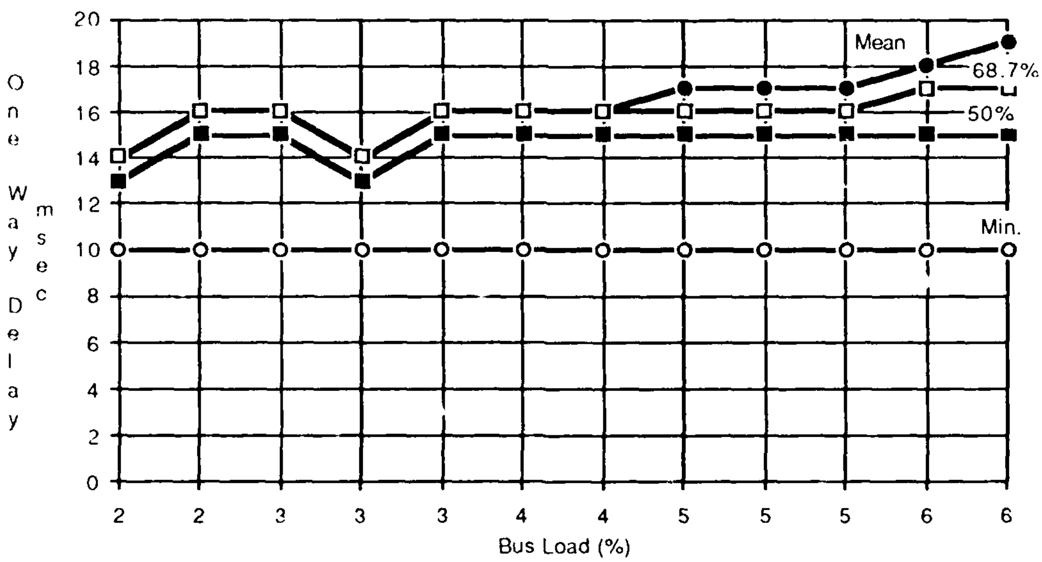
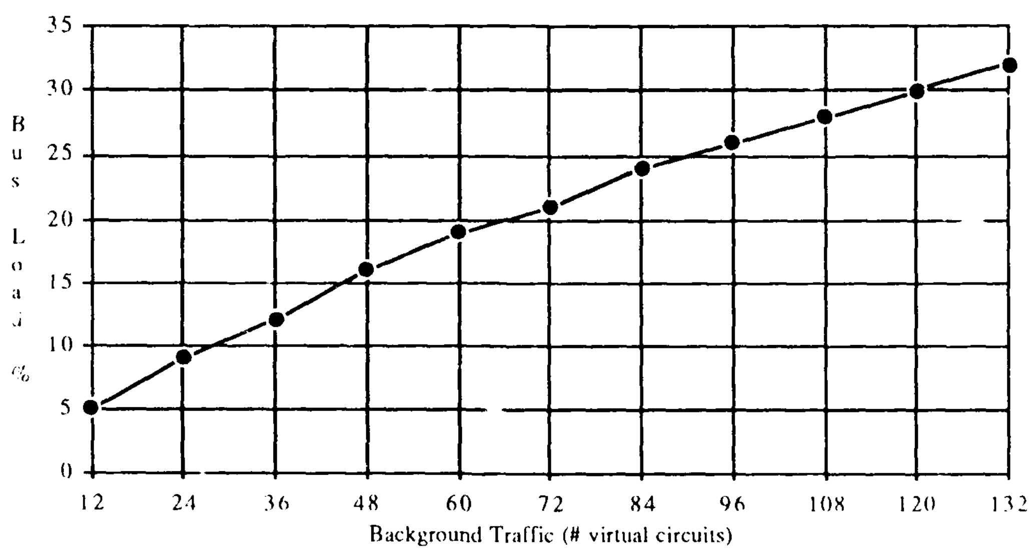




Test 4

Background Traffic (vc's)	Bus Load (%)	Mean Delay (msec)	Min. Delay (msec)	<=50% Delay (msec)	<=68.7% Delay (msec)	<=99.9% Delay (msec)	Max. Delay (msec)	Total Characters Transferred
12	5	17	10	13	14	70	127	1002
24	9	21	10	15	16	262	1048	1002
36	12	22	10	14	15	280	424	1005
48	16	30	10	16	17	429	576	1004
60	19	39	10	17	33	1196	1374	1002
72	21	41	10	17	36	1086	1936	1001
84	24	49	10	17	37	1438	1708	1002
96	26	61	10	17	45	1542	2507	1006
108	28	78	10	18	54	1844	2696	1004
120	30	90	11	34	63	2340	2766	1002
132	32	104	10	36	68	2571	2727	1003



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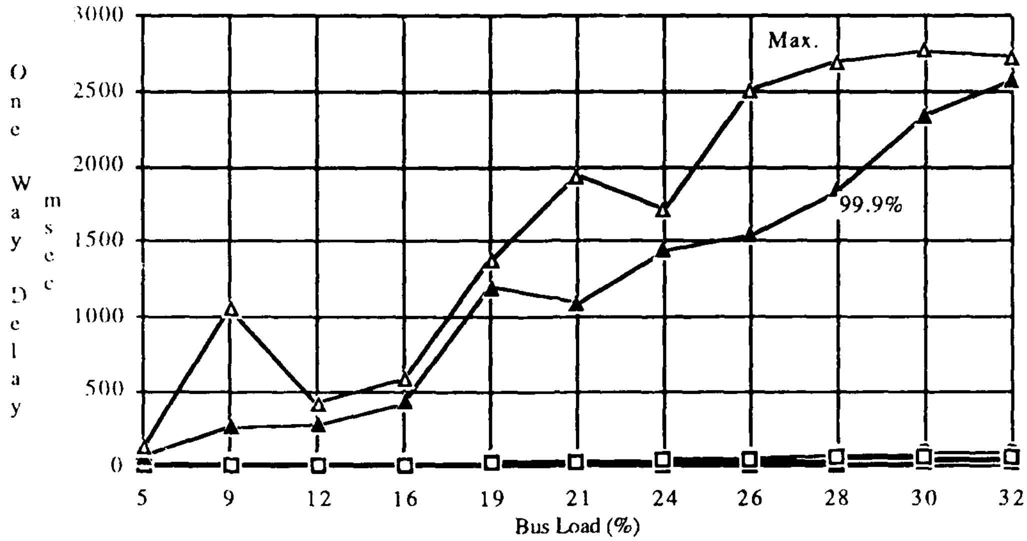

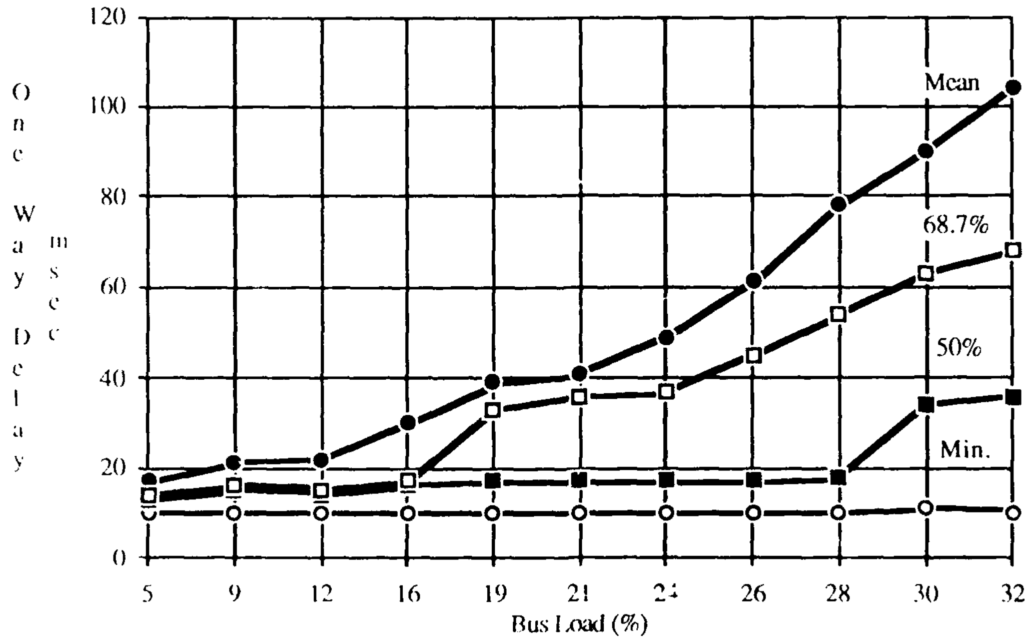

Test 5

Background Traffic (vc's)	Bus Load (%)	Mean Delay (msec)	Min. Delay (msec)	<=50% Delay (msec)	<=68.7% Delay (msec)	<=99.9% Delay (msec)	Max. Delay (msec)	Total Characters Transferred
19	5	18	10	15	16	67	68	1004
29	6	18	10	15	16	149	150	1002
38	9	22	10	15	16	161	220	1004
48	10	21	11	15	16	169	253	1003
62	12	22	10	15	16	252	544	1006
72	14	25	10	15	16	337	386	1004
83	17	25	10	15	16	232	344	1004
96	18	31	10	16	17	446	514	1010
107	20	32	10	16	17	495	867	1002
120	22	35	10	16	17	1303	1735	1003
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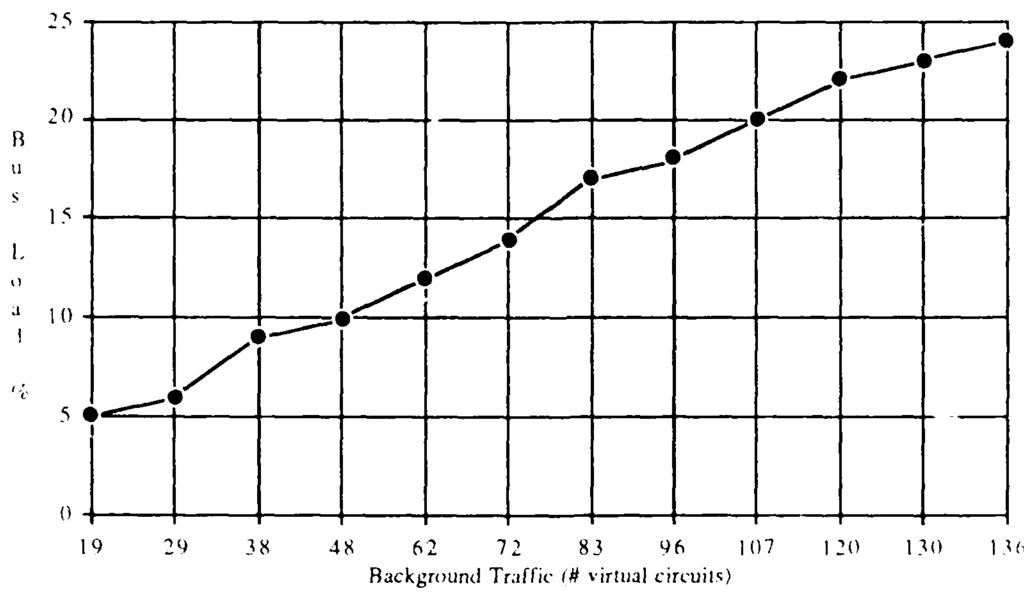

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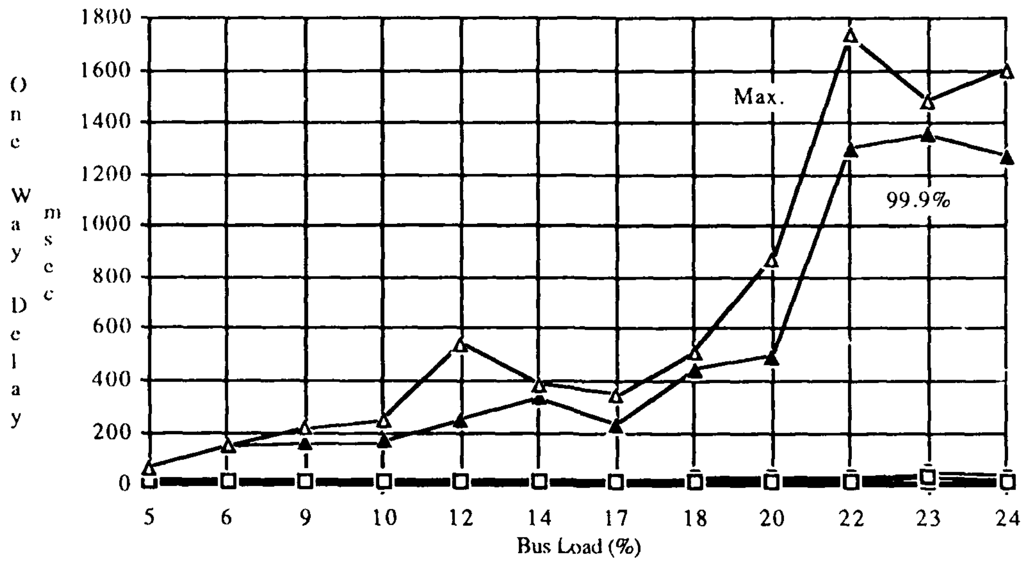

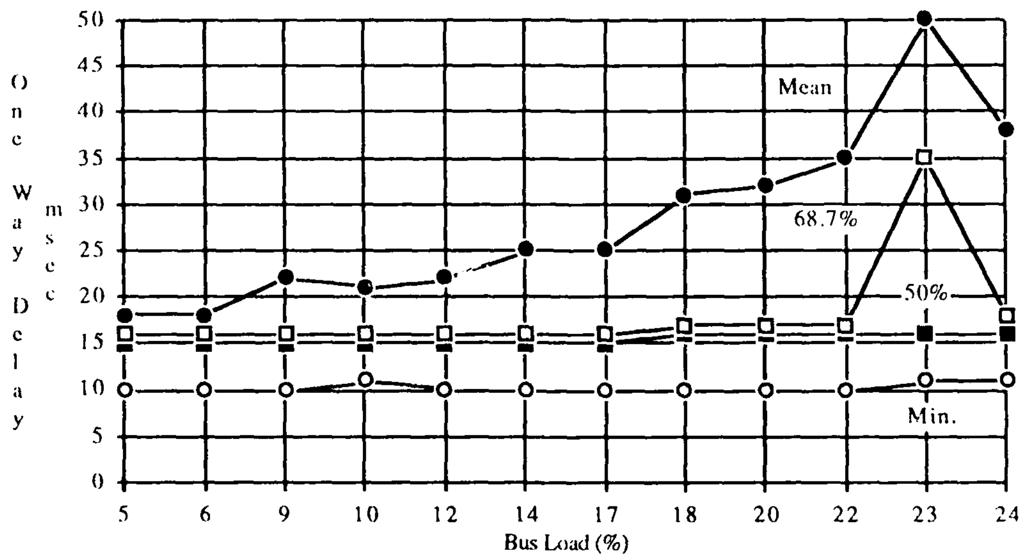

Test 6

Background Traffic (vc's)	25% Bridged Bus Load (%)	5% Unbridge Bus Load (%)	Mean Delay (msec)	Min. Delay (msec)	<=50% Delay (msec)	<=68.7% Delay (msec)	<=99.9% Delay (msec)	Max. Delay (msec)	Total Characters Transferred
12	4	11	18	10	13	14	232	272	1001
24	4	17	28	10	16	17	513	749	1003
36	6	20	36	10	16	18	729	926	998
48	6	28	44	10	15	41	1030	1343	1004
60	7	30	65	10	17	45	1957	2048	1003
72	7	32	74	10	18	55	1427	1511	1004
84	11	36	81	10	19	57	2204	2279	1002
96	13	39	120	10	36	66	2374	2871	1004
108	15	41	100	10	36	65	2734	2962	1002
120	13	42	140	10	34	65	3129	3168	1001
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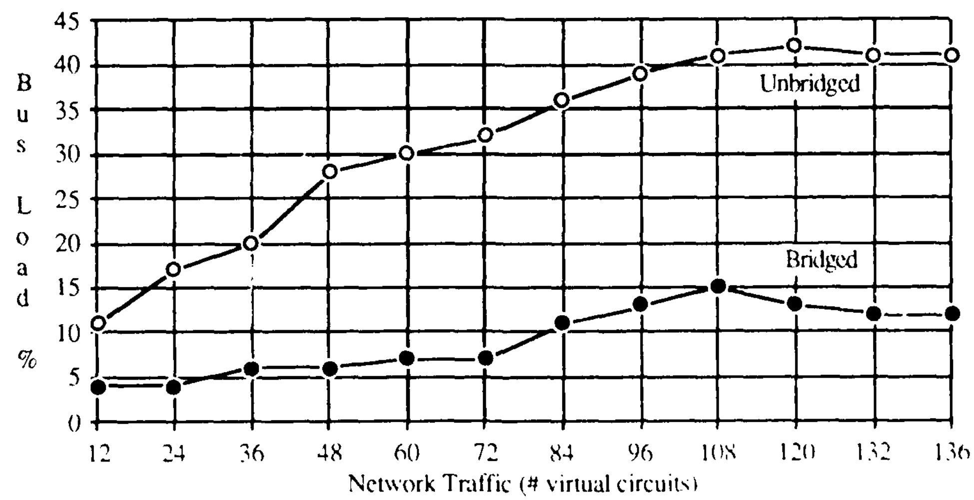

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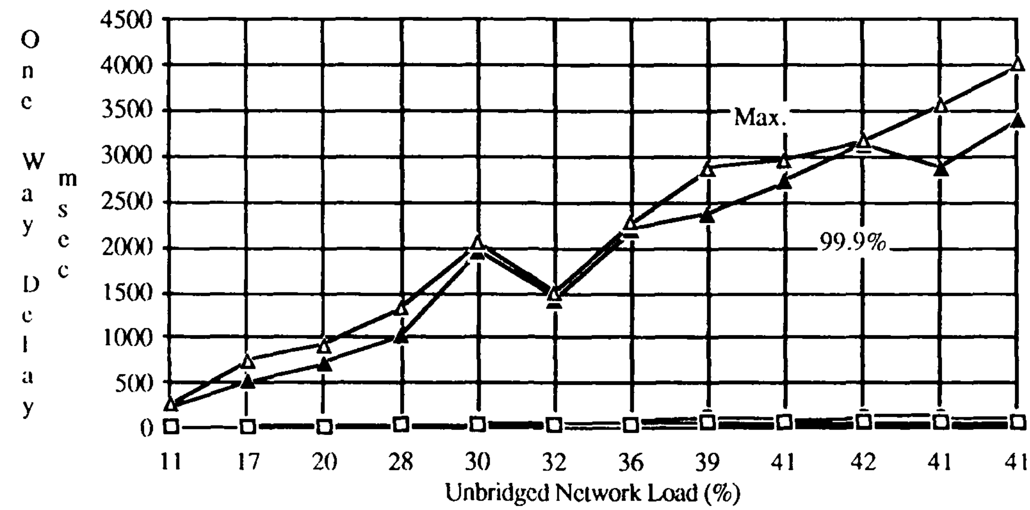
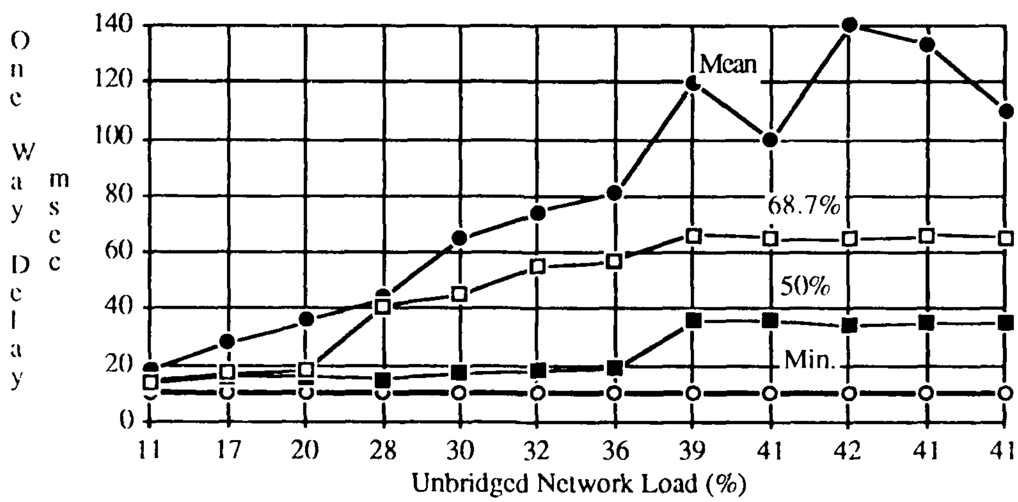
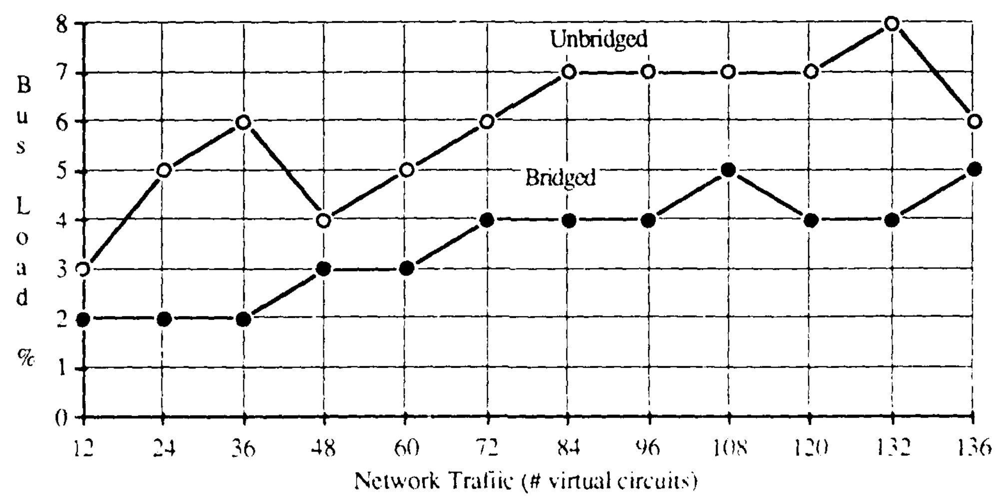




Test 7

Background Traffic (vc's)	25% Bridged Bus Load (%)	5% Unbridged Bus Load (%)	Mean Delay (msec)	Min. Delay (msec)	<=50% Delay (msec)	<=68.7% Delay (msec)	<=99.9% Delay (msec)	Max. Delay (msec)	Total Characters Transferred
12	2	3	16	10	15	15	55	67	1003
24	2	5	16	10	15	15	63	86	105
36	2	6	16	10	15	16	69	98	1001
48	3	4	16	10	15	16	67	138	1004
60	3	5	17	10	15	16	68	109	1005
72	4	6	17	10	15	16	86	87	1004
84	4	7	17	10	15	16	97	304	1003
96	4	7	18	10	15	16	87	148	1005
108	5	7	17	10	15	16	108	149	1003
120	4	7	18	10	15	16	129	243	1000
132	4	8	17	10	13	14	211	260	1005
136	5	6	17	10	15	16	128	240	1001



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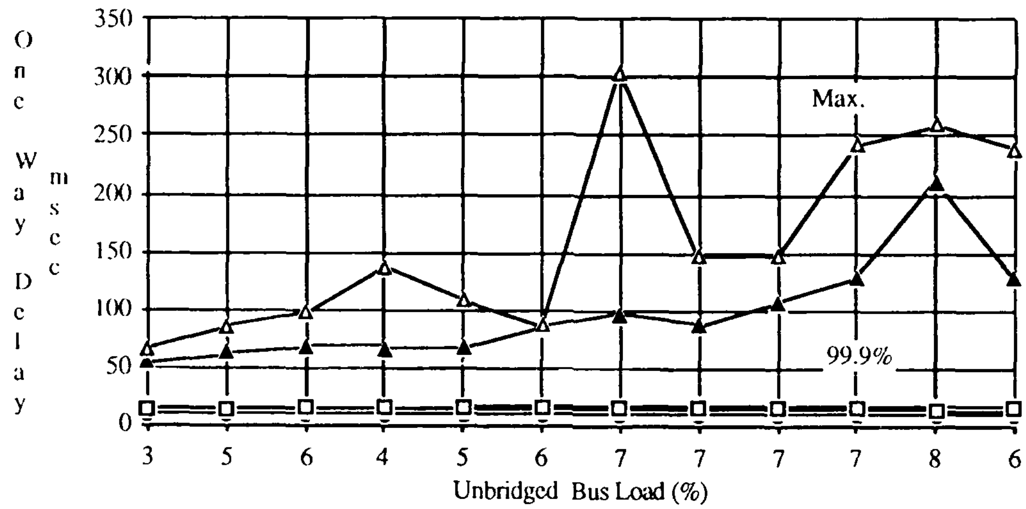
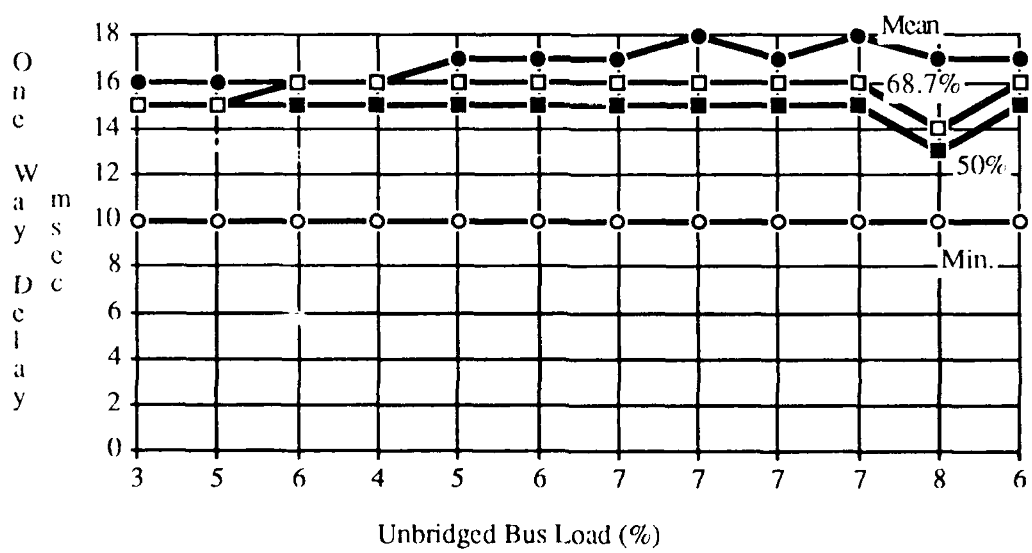
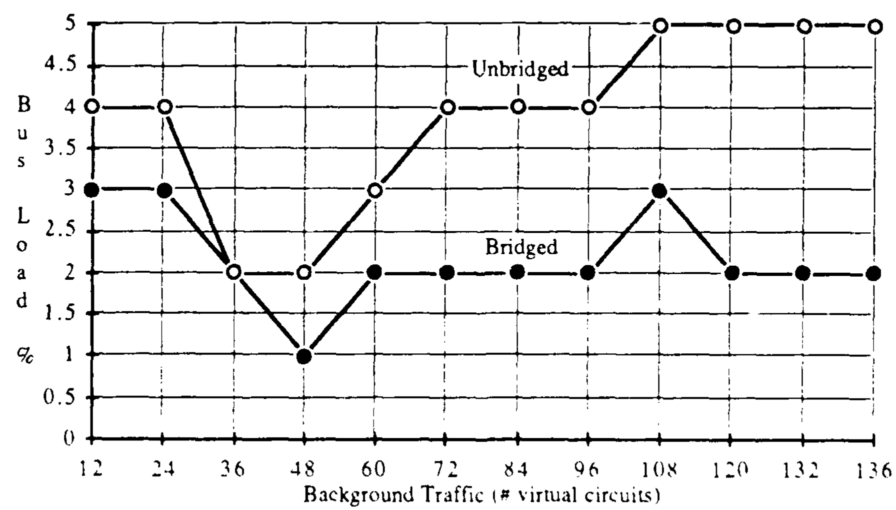




Test 8

Background Traffic (vc's)	25% Bridged Bus Load (%)	5% Unbridged Bus Load (%)	Mean Delay (msec)	Min. Delay (msec)	<=50% Delay (msec)	<=68.7% Delay (msec)	<=99.9% Delay (msec)	Max. Delay (msec)	Total Characters Transferred
12	3	4	14	11	13	14	63	65	972
24	3	4	16	10	15	15	36	63	1001
36	2	2	16	10	15	16	66	68	1000
48	1	2	16	10	15	16	63	87	1000
60	2	3	16	10	15	15	56	64	1002
72	2	4	17	10	15	16	67	68	1002
84	2	4	17	10	15	16	98	128	1000
96	2	4	16	10	15	16	67	69	1002
108	3	5	17	10	15	16	67	77	1000
120	2	5	17	10	15	16	67	67	965
132	2	5	17	10	15	16	74	84	1041
136	2	5	18	10	15	16	146	223	1000



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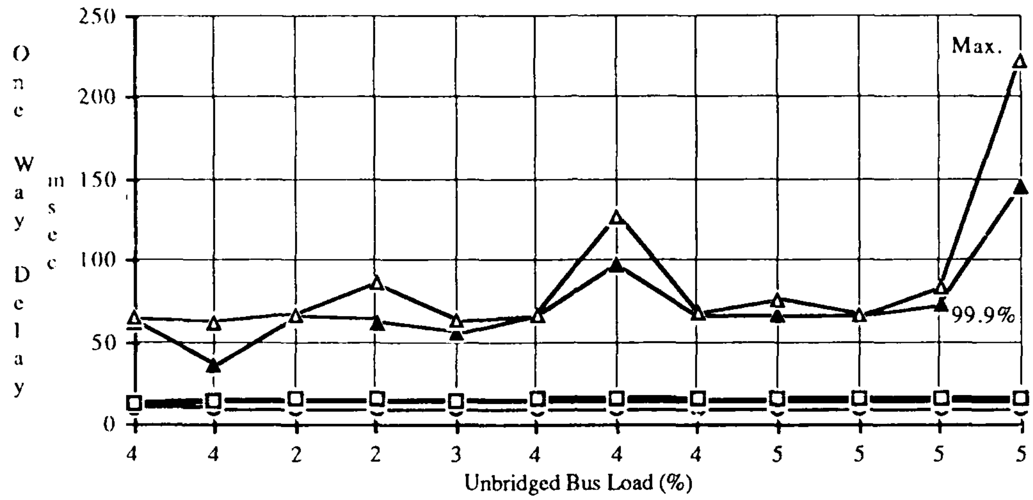
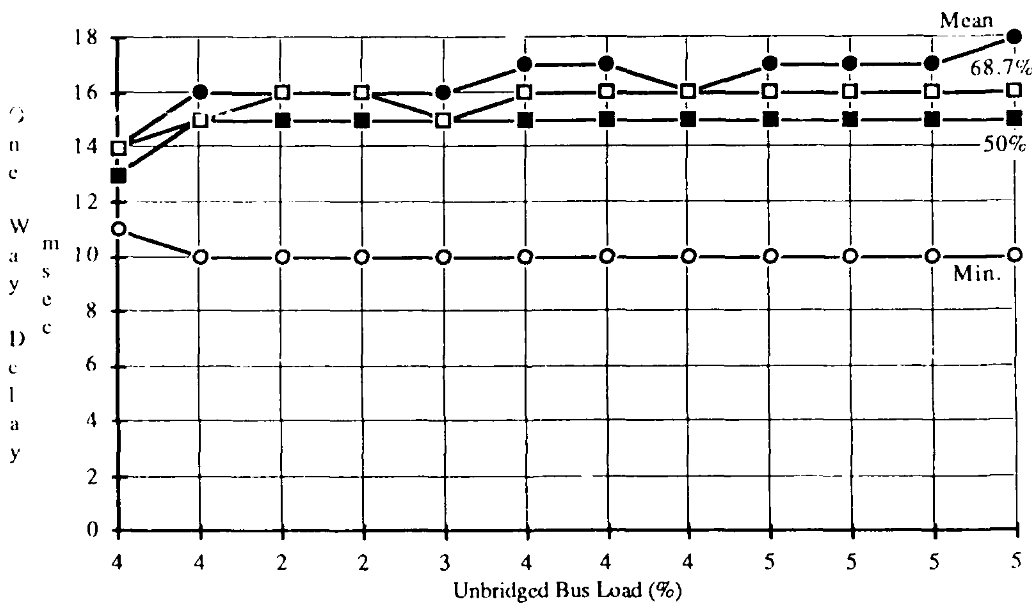
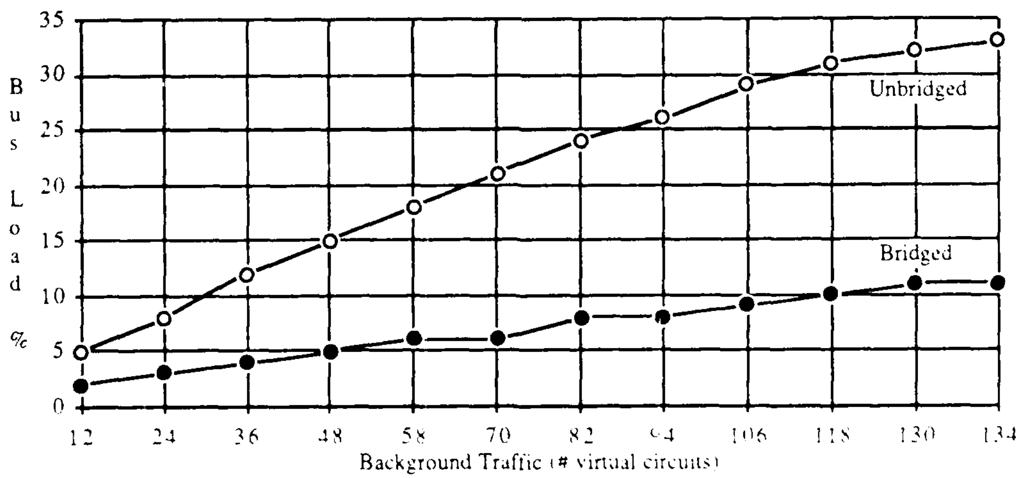




Test 9

Backgroun Traffic (vc's)	25% Bridge Bus Load (%)	5% Unbridge Bus Load (%)	Mean Delay (msec)	Min. Delay (msec)	<=50% Delay (msec)	<=68.7% Delay (msec)	<=99.9% Delay (msec)	Max. Delay (msec)	Total Characters Transferred
12	2	5	16	10	13	14	126	147	999
24	3	8	20	10	12	15	164	310	1004
36	4	12	25	10	14	17	260	431	1005
48	5	15	30	10	14	19	342	510	1004
58	6	18	35	10	14	19	951	1684	1004
70	6	21	44	10	15	19	1683	1717	1002
82	8	24	46	10	15	32	898	2845	1003
94	8	26	81	10	17	52	2018	2241	1001
106	9	29	84	10	19	55	1741	2004	1004
118	10	31	104	10	32	59	3311	3461	1001
130	11	32	118	10	33	62	2459	3415	1001
134	11	33	129	10	33	64	2644	3871	1004



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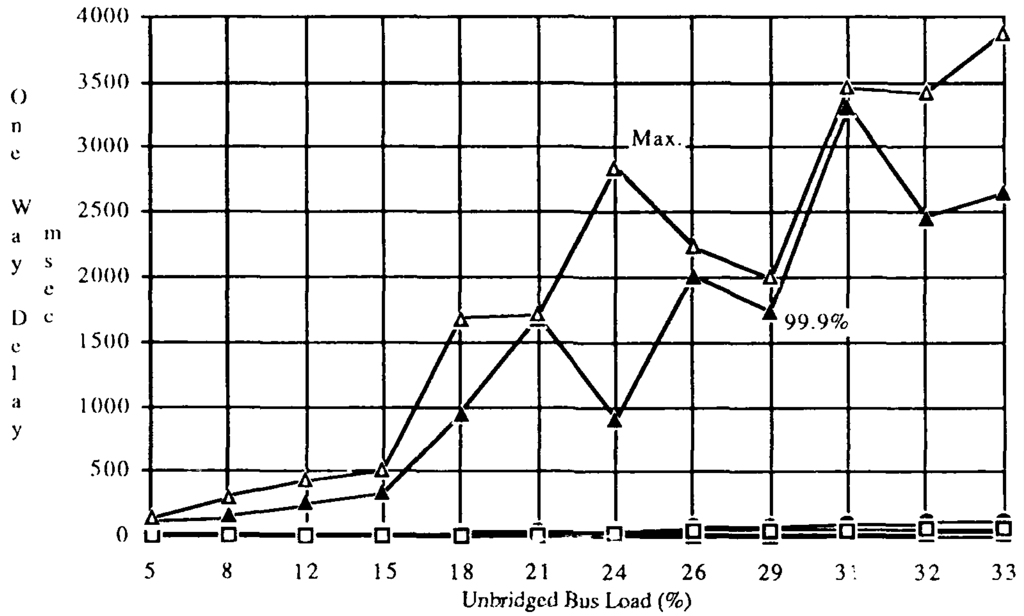
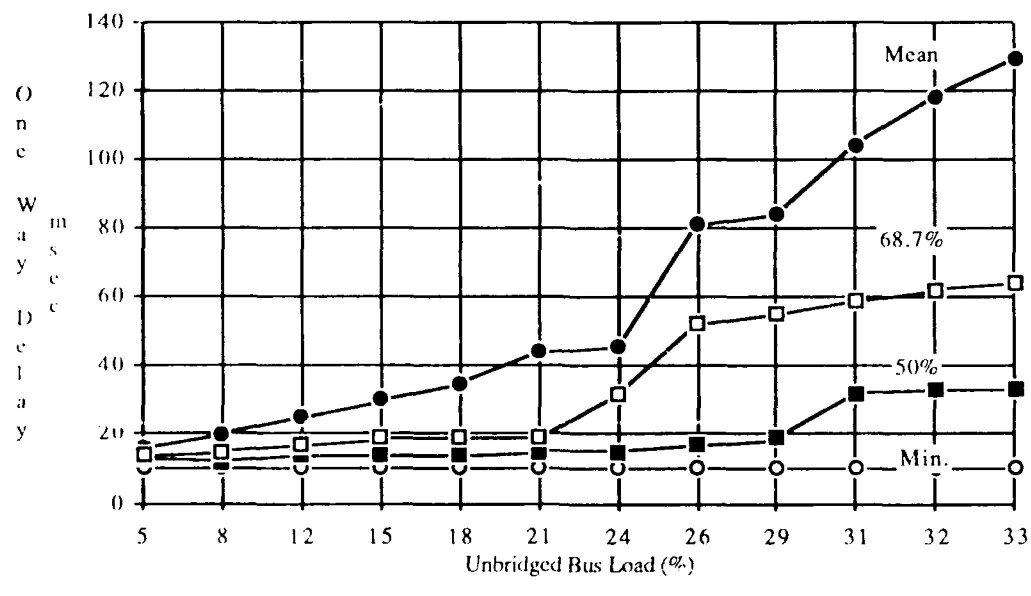
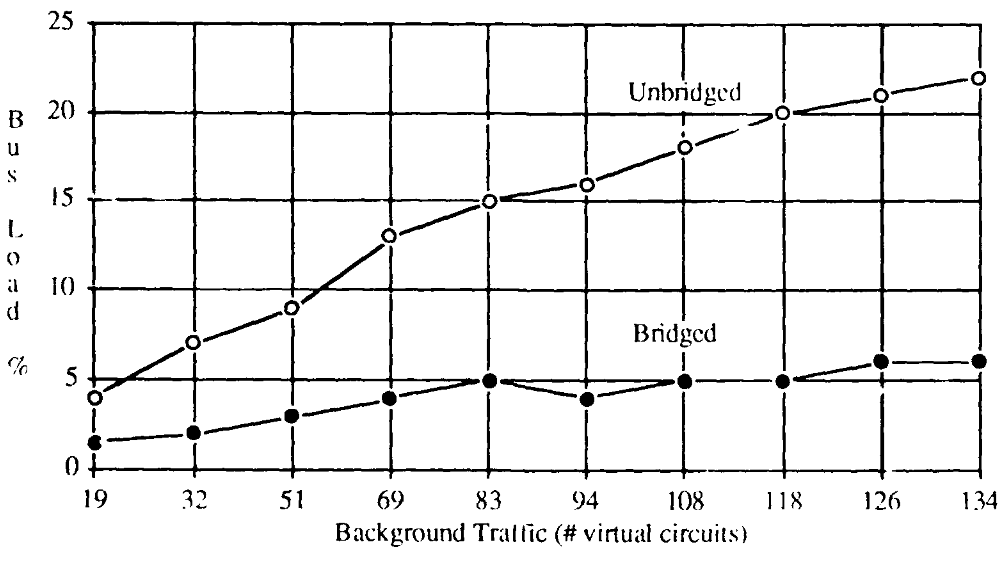




Test 10

Background Traffic (vc's)	25% Load Bridged (%)	75% Load Local (%)	Mean Delay (msec)	Min. Delay (msec)	<=50% Delay (msec)	<=68.7% Delay (msec)	<=99.9% Delay (msec)	Max. Delay (msec)	Total Characters Transferred
19	1.5	4	16	10	13	14	109	115	1004
32	2	7	17	10	13	14	106	113	1004
51	3	9	21	10	14	15	251	275	1006
69	4	13	27	10	14	17	529	579	1005
83	5	15	25	10	14	17	345	374	1003
94	4	16	27	10	14	18	322	359	1006
108	5	18	36	10	15	19	823	1862	1002
118	5	20	41	10	15	30	962	1849	1003
126	6	21	38	10	14	19	1705	1982	1002
134	6	22	43	10	15	34	1169	1219	1005



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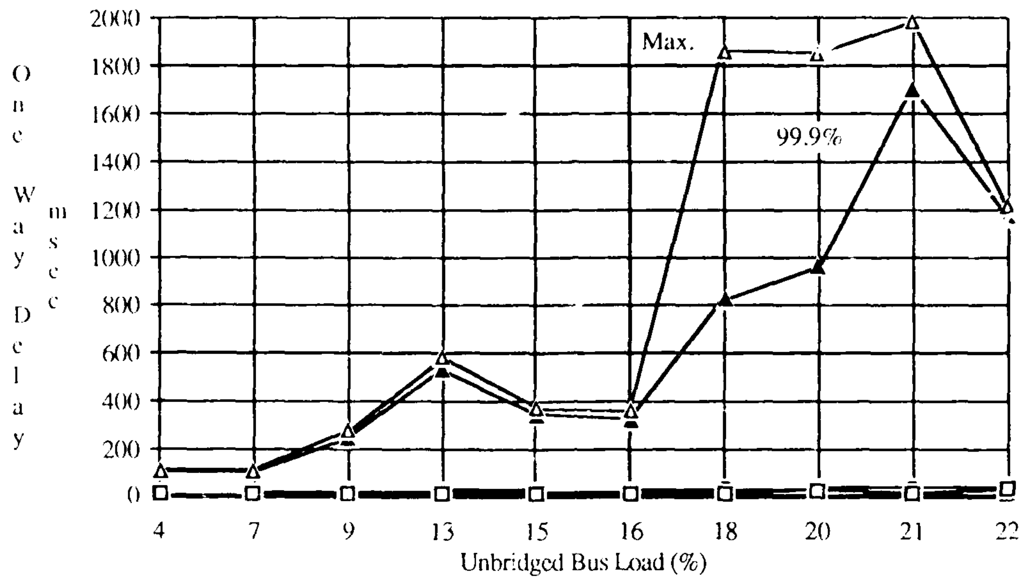
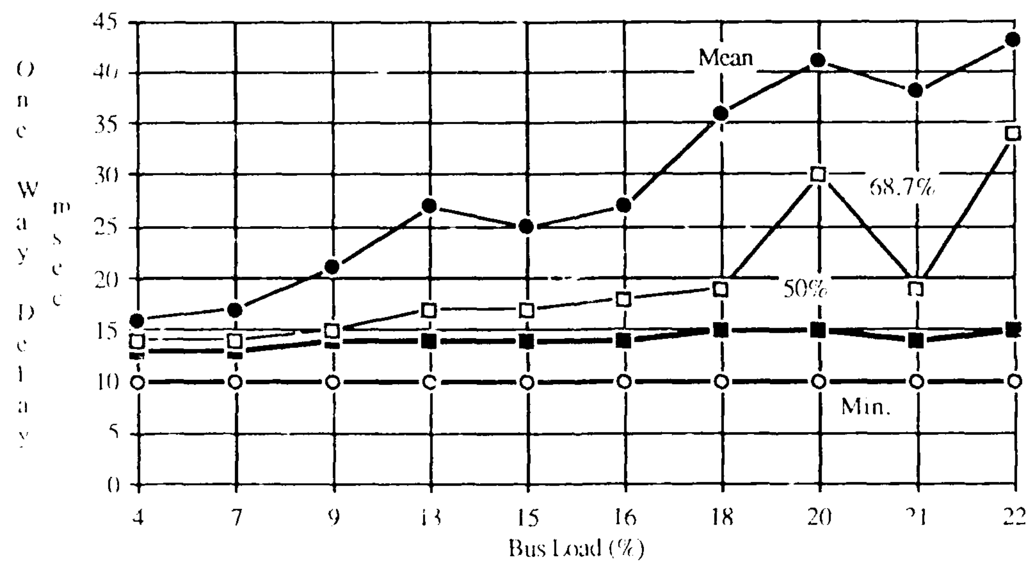
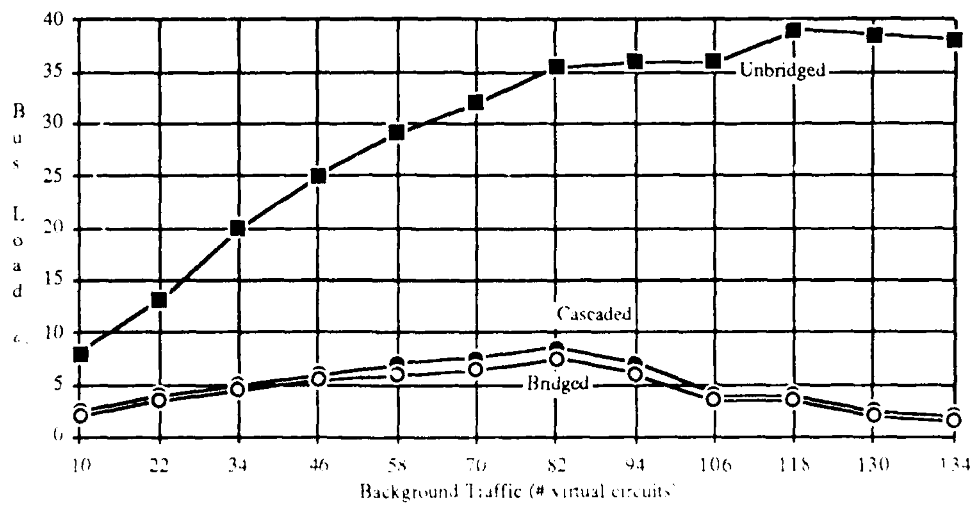


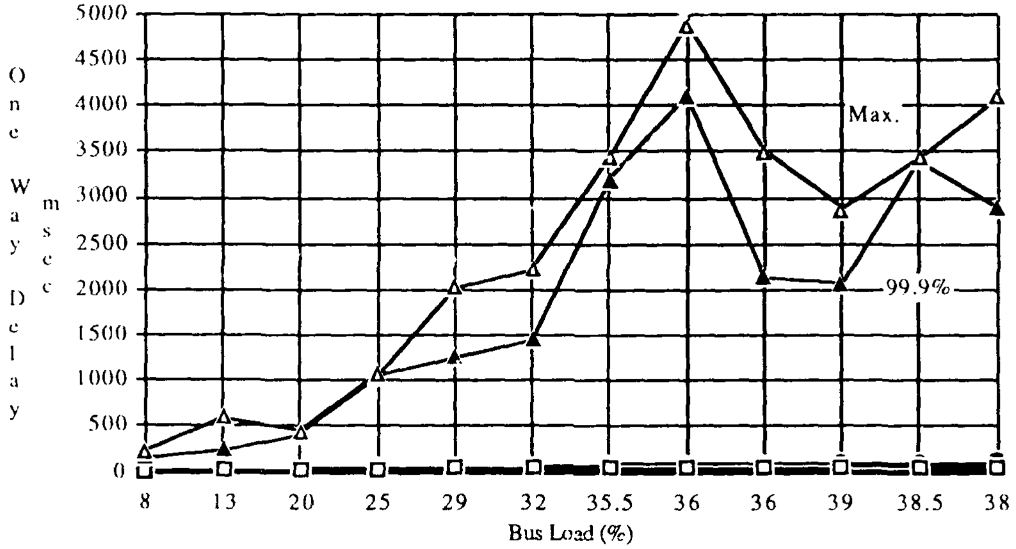


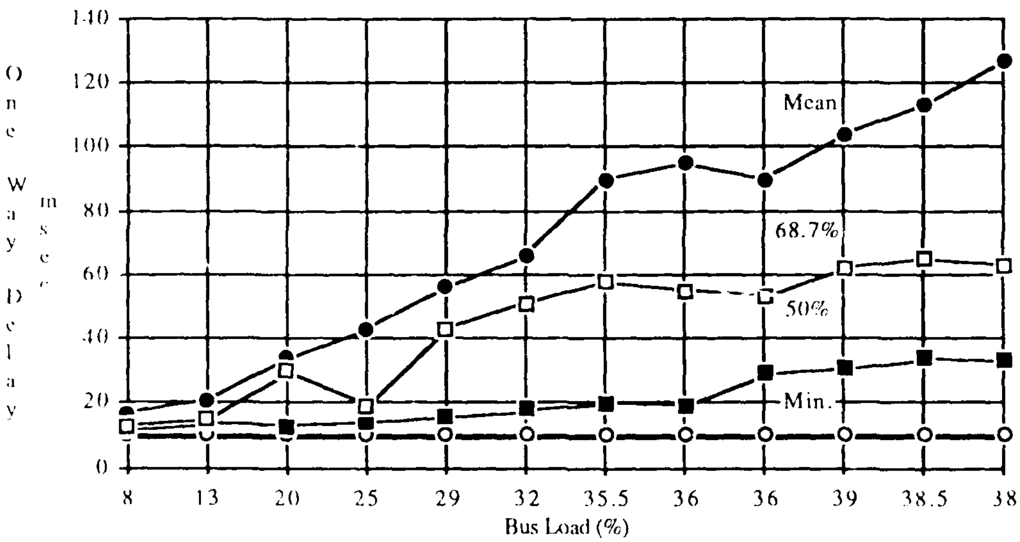
Test 11

Background Traffic (vc's)	Cascade Load (%)	25% Load Bridged (%)	75% Load Local (%)	Mean Delay (msec)	Min. Delay (msec)	<=50% Delay (msec)	<=68.7% Delay (msec)	<=99.9% Delay (msec)	Max. Delay (msec)	Total Characters Transferred
10	2.5	2	8	17	10	12	13	153	225	1003
22	4	3.5	13	21	10	14	15	239	598	1002
34	5	4.5	20	34	10	13	30	423	455	1002
46	6	5.5	25	43	10	14	19	1053	1064	1006
58	7	6	29	56	10	16	43	1253	2035	1005
70	7.5	6.5	32	66	10	18	51	1456	2235	1005
82	8.5	7.5	35.5	90	10	20	58	3200	3429	1004
94	7	6	36	95	10	19	55	4090	4882	1000
106	4	3.5	36	90	10	29	53	2136	3498	1004
118	4	3.5	39	104	10	31	62	2062	2867	1005
130	2.5	2	38.5	113	10	34	65	3412	3437	1003
134	2	1.5	38	127	10	33	63	2891	4093	1005



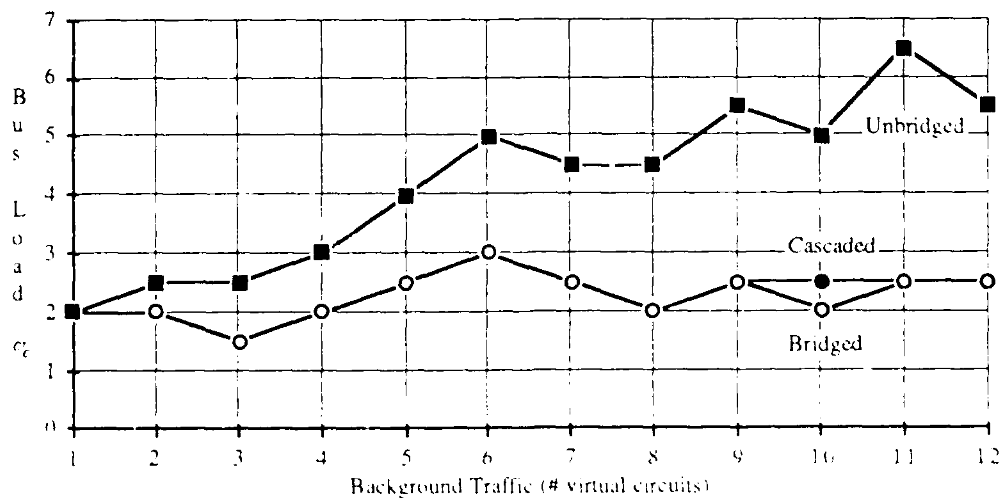
Test 11 (concluded)



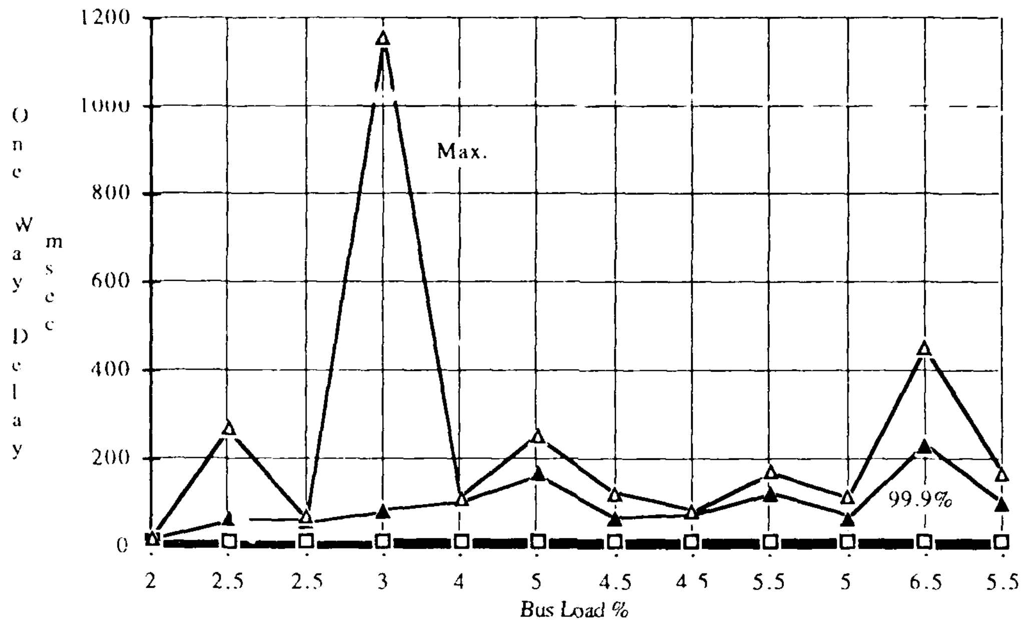


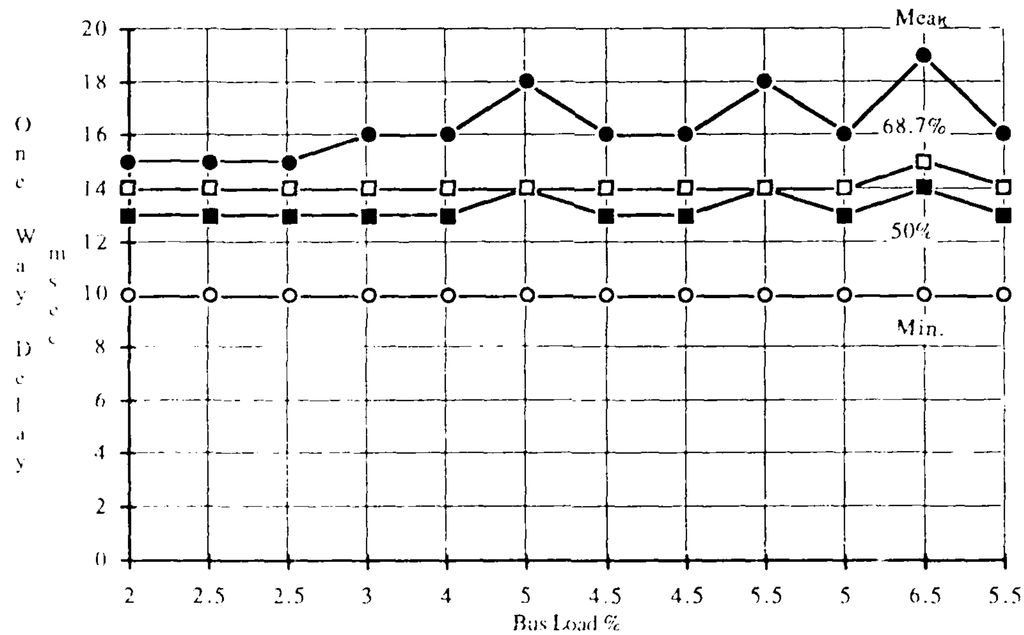
Test 12

Background Traffic (vc's)	Cascaded Load (%)	25% Load Bridged (%)	75% Load Local (%)	Mean Delay (msec)	Min. Delay (msec)	<=50% Delay (msec)	<=68.7% Delay (msec)	<=99.9% Delay (msec)	Max. Delay (msec)	Total Characters Transferred
12	2	2	2	15	10	13	14	20	20	1001
24	2	2	2.5	15	10	13	14	65	271	1005
36	1.5	1.5	2.5	15	10	13	14	61	70	1000
48	2	2	3	16	10	13	14	85	1159	1001
60	2.5	2.5	4	16	10	13	14	106	114	1002
72	3	3	5	18	10	14	14	168	254	1001
84	2.5	2.5	4.5	16	10	13	14	69	126	1004
96	2	2	4.5	16	10	13	14	76	84	1000
108	2.5	2.5	5.5	18	10	14	14	125	174	1002
120	2.5	2	5	16	10	13	14	69	116	1002
132	2.5	2.5	6.5	19	10	14	15	235	453	1002
136	2.5	2.5	5.5	16	10	13	14	99	171	1002



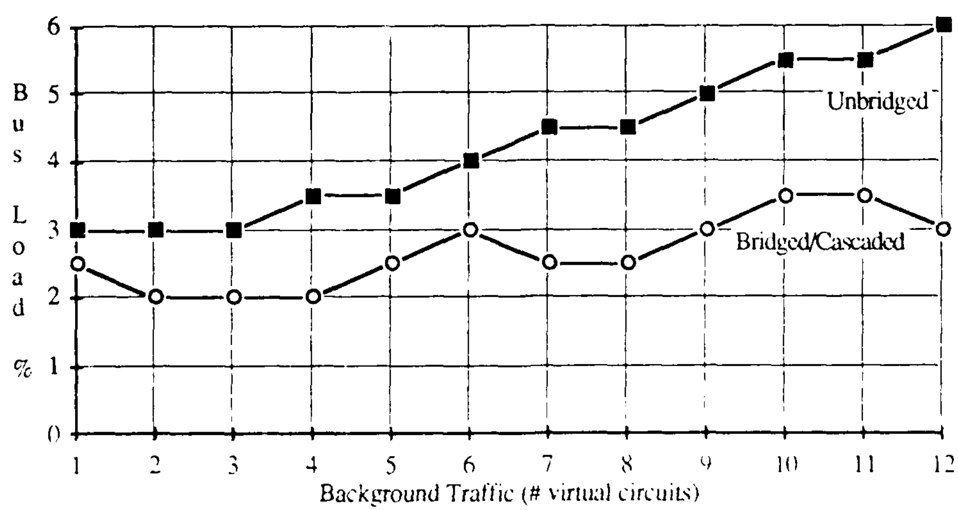
Test 12 (concluded)



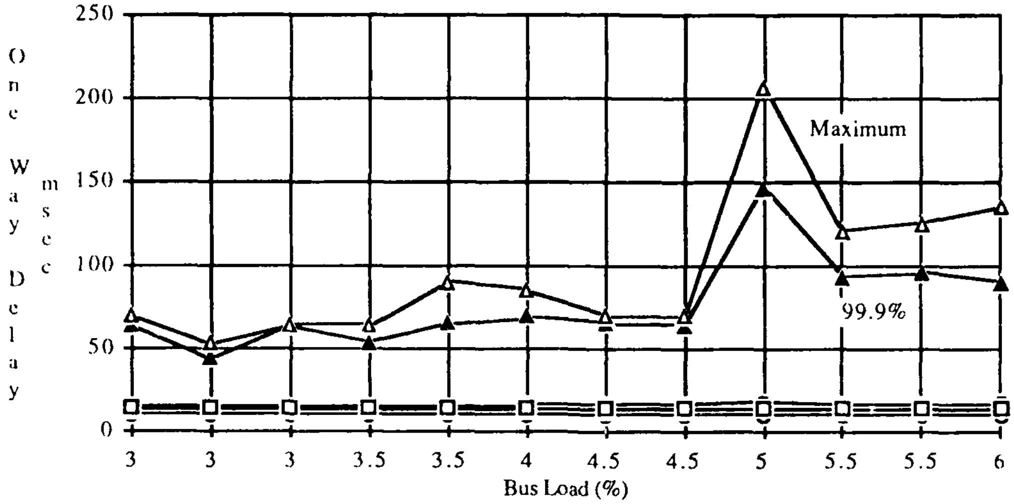


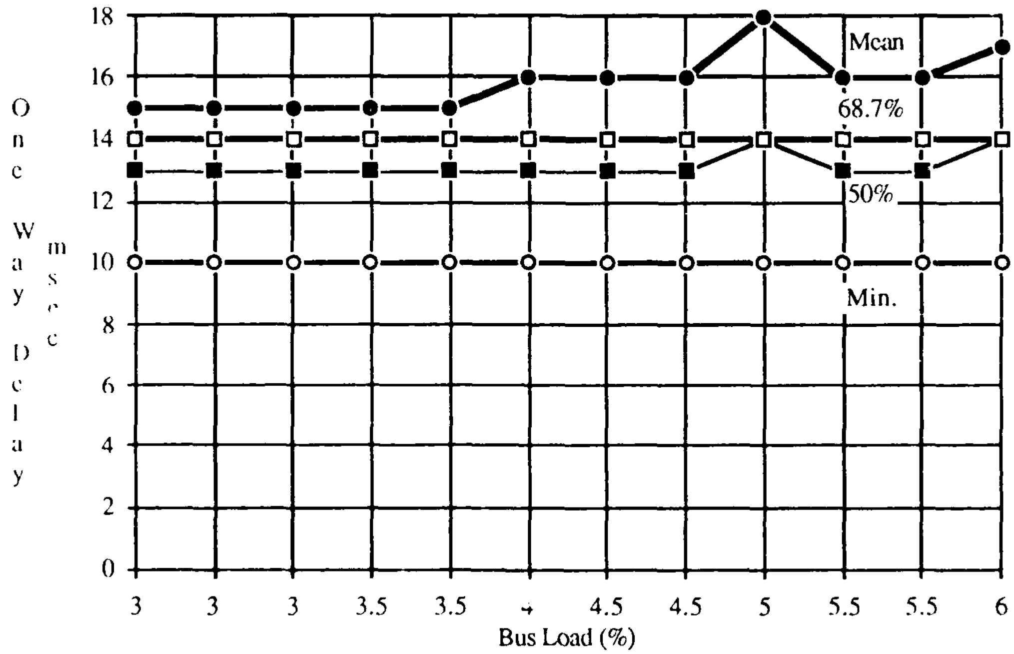
Test 13

Backgroun Traffic (vc's)	Cascade Load (%)	25% Load Bridged (%)	75% Load Local (%)	Mean Delay (msec)	Min. Delay (msec)	<=50% Delay (msec)	<=68.7% Delay (msec)	<=99.9% Delay (msec)	Max. Delay (msec)	Total Characters Transferred
12	2.5	2.5	3	15	10	13	14	64	70	1003
24	2	2	3	15	10	13	14	44	53	1001
36	2	2	3	15	10	13	14	64	65	1002
48	2	2	3.5	15	10	13	14	54	64	1002
60	2.5	2.5	3.5	15	10	13	14	66	91	1002
72	3	3	4	16	10	13	14	70	85	1000
84	2.5	2.5	4.5	16	10	13	14	66	70	1002
96	2.5	2.5	4.5	16	10	13	14	65	70	1002
108	3	3	5	18	10	14	14	147	208	1003
120	3.5	3.5	5.5	16	10	13	14	94	121	1004
1[illegible]2	3.5	3.5	5.5	16	10	13	14	97	126	1001
136	3	3	6	17	10	14	14	90	136	1004



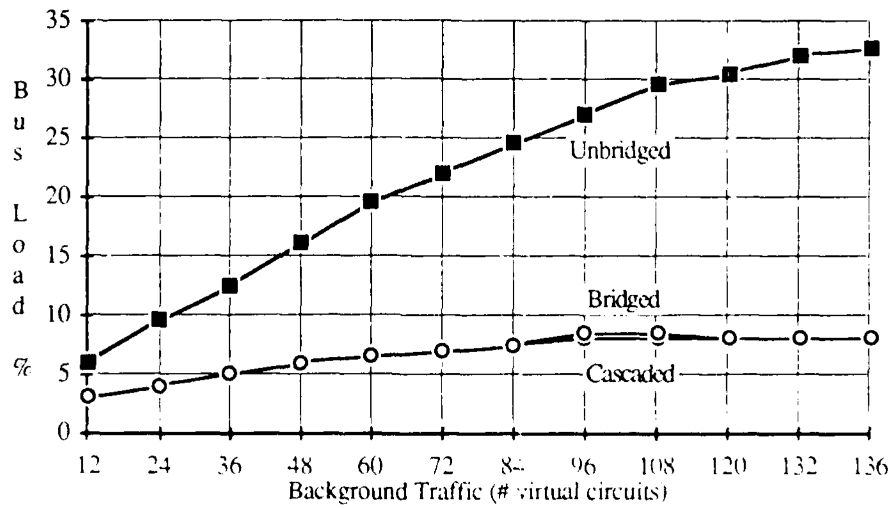
Test 13 (concluded)



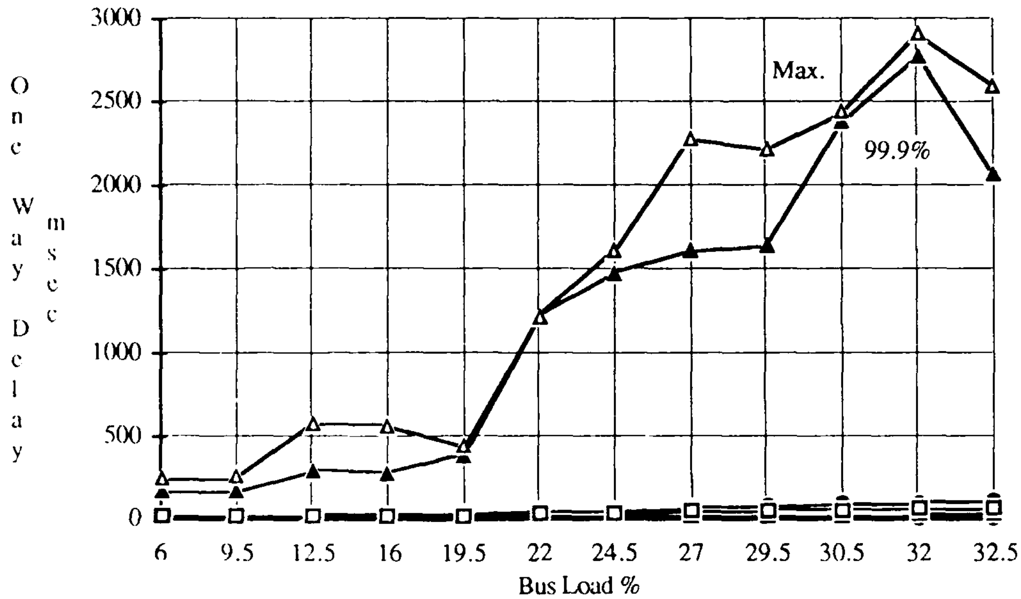


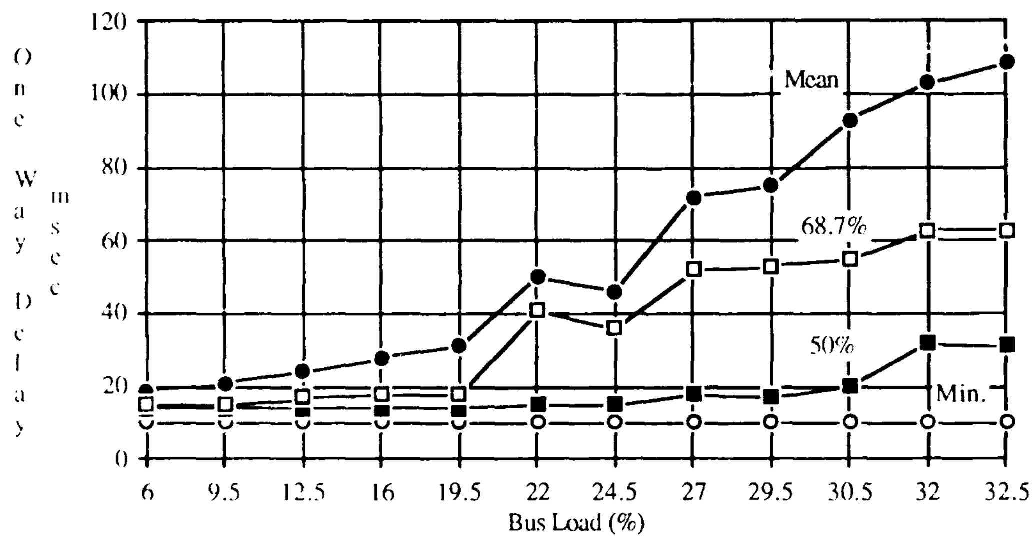
Test 14

Background Traffic (vc's)	Cascade Load (%)	25% Load Bridged (%)	75% Load Local (%)	Mean Delay (msec)	Min. Delay (msec)	<=50% Delay (msec)	<=68.7% Delay (msec)	<=99.9% Delay (msec)	Max. Delay (msec)	Total Characters Transferred
12	3	3	6	19	10	14	15	171	249	1002
24	4	4	9.5	21	10	14	15	167	261	1004
36	5	5	12.5	24	10	14	17	298	580	1001
48	6	6	16	28	10	14	18	282	566	1000
60	6.5	6.5	19.5	31	10	14	18	388	442	1004
72	7	7	22	50	10	15	41	1220	1221	1004
84	7.5	7.5	24.5	46	10	15	36	1477	1606	1003
96	8	8.5	27	72	10	18	52	1604	2273	1003
108	8	8.5	29.5	75	10	17	53	1640	2210	1001
120	8	8	30.5	93	10	20	55	2378	2436	1003
132	8	8	32	103	10	32	63	2780	2907	1001
136	8	8	32.5	109	10	31	63	2063	2601	1001



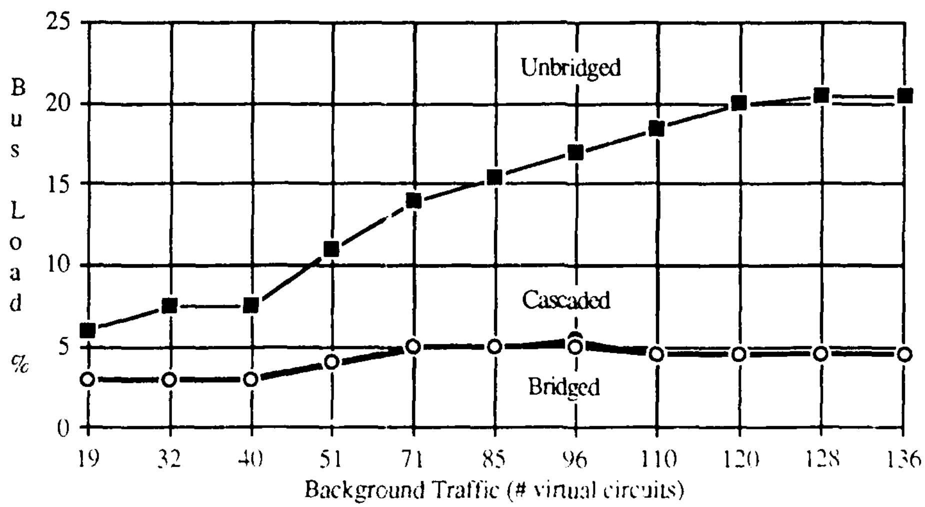
Test 14 (concluded)



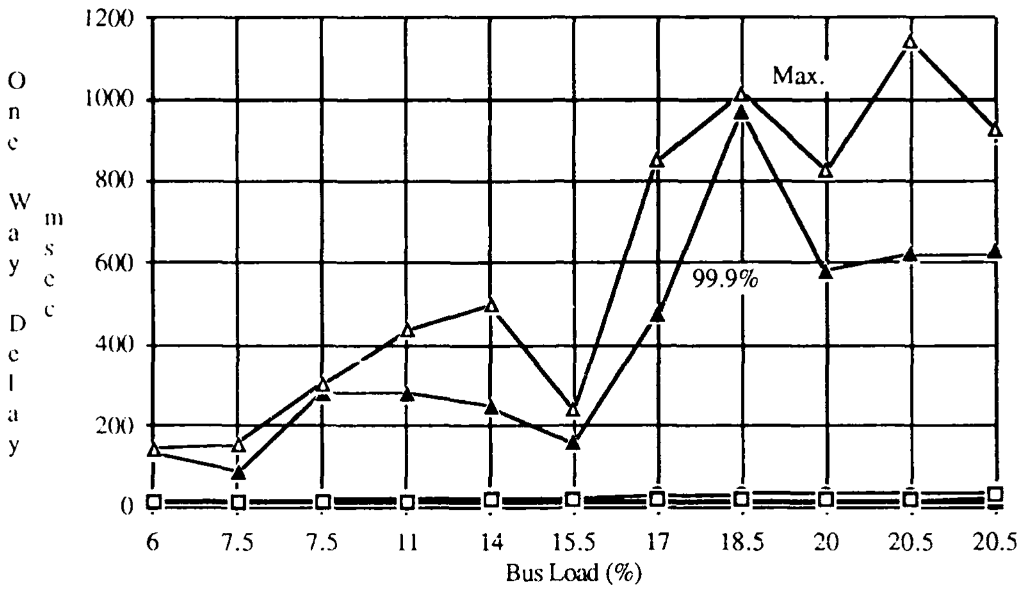


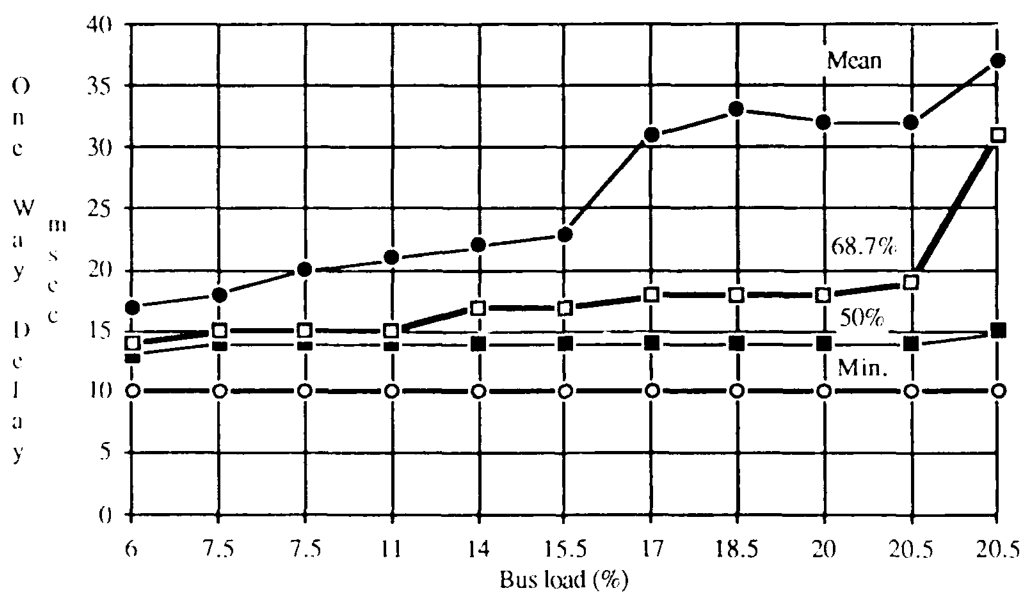
Test 15

Backgroun Traffic (vc's)	Cascade Load (%)	25% Load Bridged (%)	75% Load Local (%)	Mean Delay (msec)	Min. Delay (msec)	<=50% Delay (msec)	<=68.7% Delay (msec)	<=99.9% Delay (msec)	Max. Delay (msec)	Total Characters Transferred
19	3	3	6	17	10	13	14	134	144	1001
32	3	3	7.5	18	10	14	15	85	156	1001
40	3	3	7.5	20	10	14	15	281	302	1000
51	4	4	11	21	10	14	15	281	436	1001
71	5	5	14	22	10	14	17	246	498	1002
85	5	5	15.5	23	10	14	17	159	239	1003
96	5.5	5	17	31	10	14	18	475	849	1004
110	4.5	4.5	18.5	33	10	14	18	968	1015	1004
120	4.5	4.5	20	32	10	14	18	582	827	1002
128	4.5	4.5	20.5	32	10	14	19	622	1141	1000
136	4.5	4.5	20.5	37	10	15	31	627	928	1004



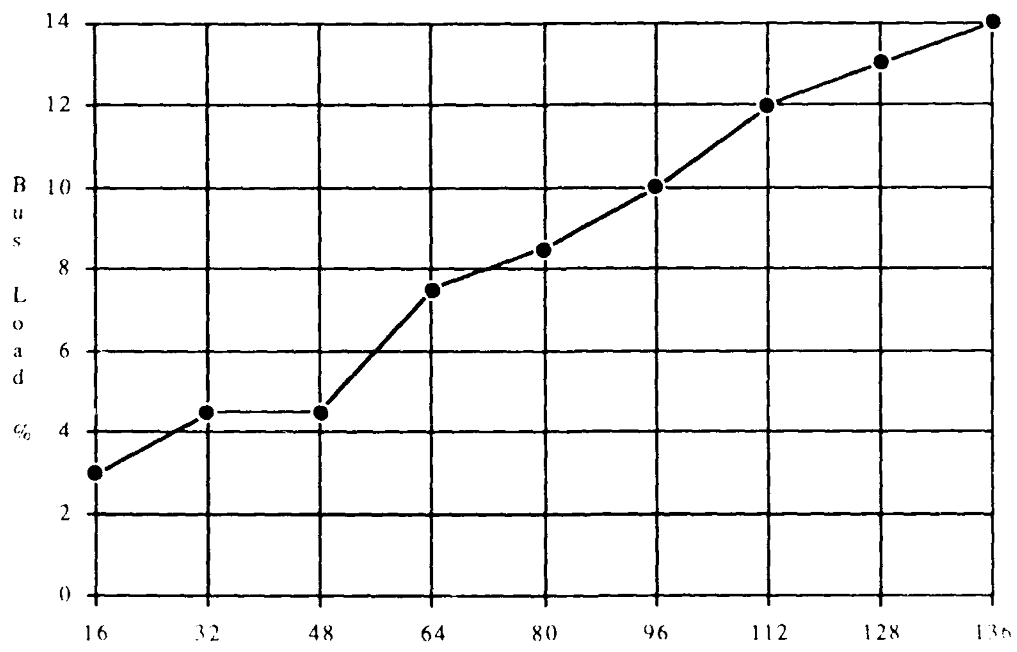
Test 15 (concluded)



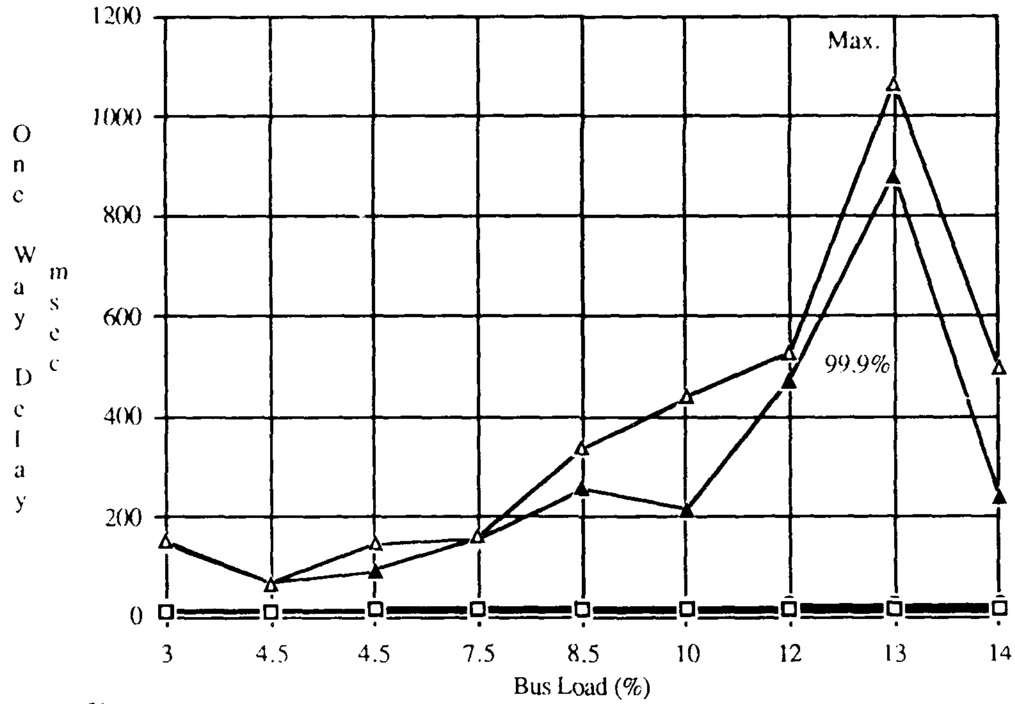


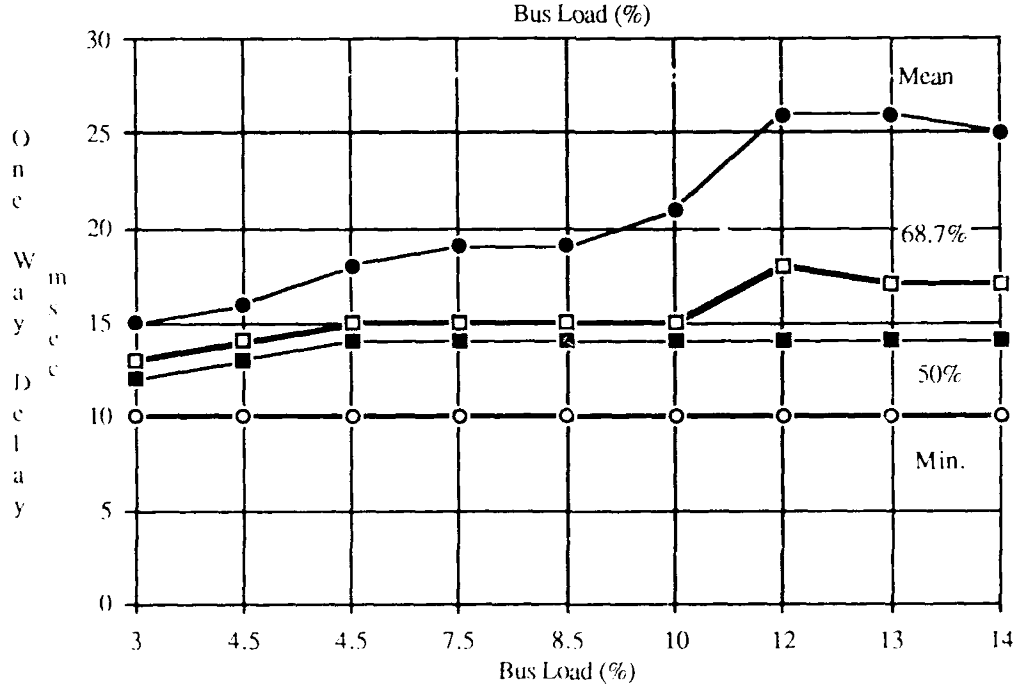
Test 16

Background Traffic (vc's)	Unbridged Bus Load (%)	Mean Delay (msec)	Min. Delay (msec)	<=50% Delay (msec)	<=68.7% Delay (msec)	<=99.9% Delay (msec)	Max. Delay (msec)	Total Characters Transferred
16	3	15	10	12	13	147	152	1002
32	4.5	16	10	13	14	69	69	1001
48	4.5	18	10	14	15	93	147	1003
64	7.5	19	10	14	15	158	162	1002
80	8.5	19	10	14	15	259	339	1004
96	10	21	10	14	15	214	440	1003
112	12	26	10	14	18	473	528	1005
128	13	26	10	14	17	878	1064	1004
136	14	25	10	14	17	240	498	1003



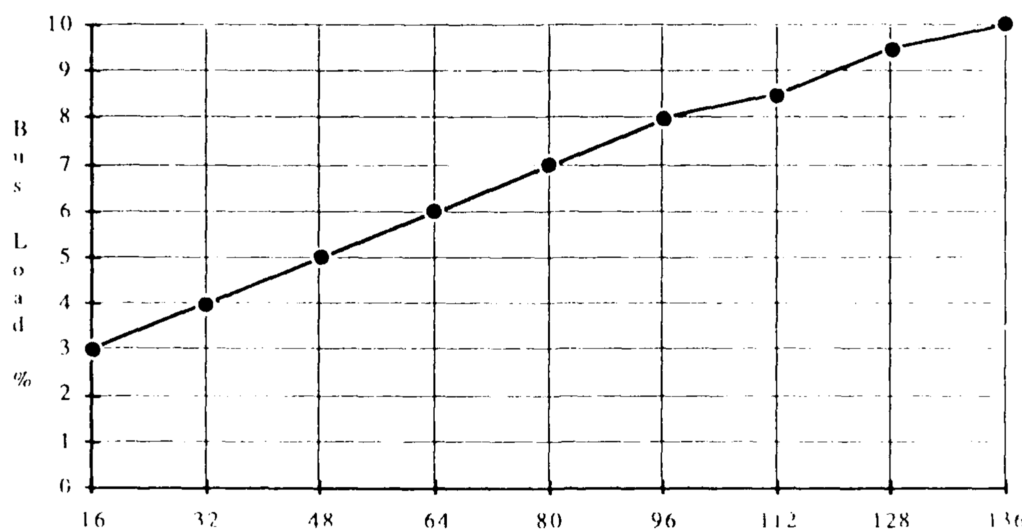
Test 16 (concluded)



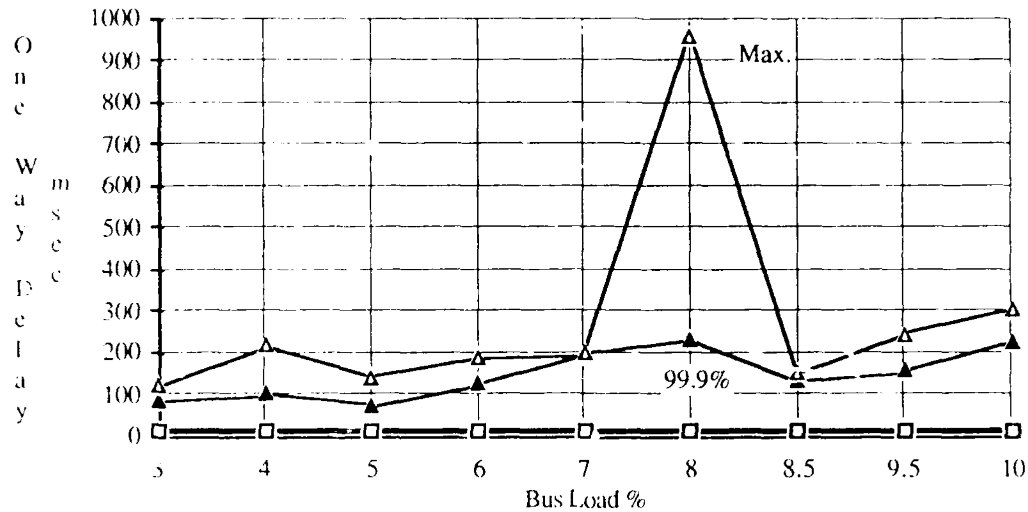


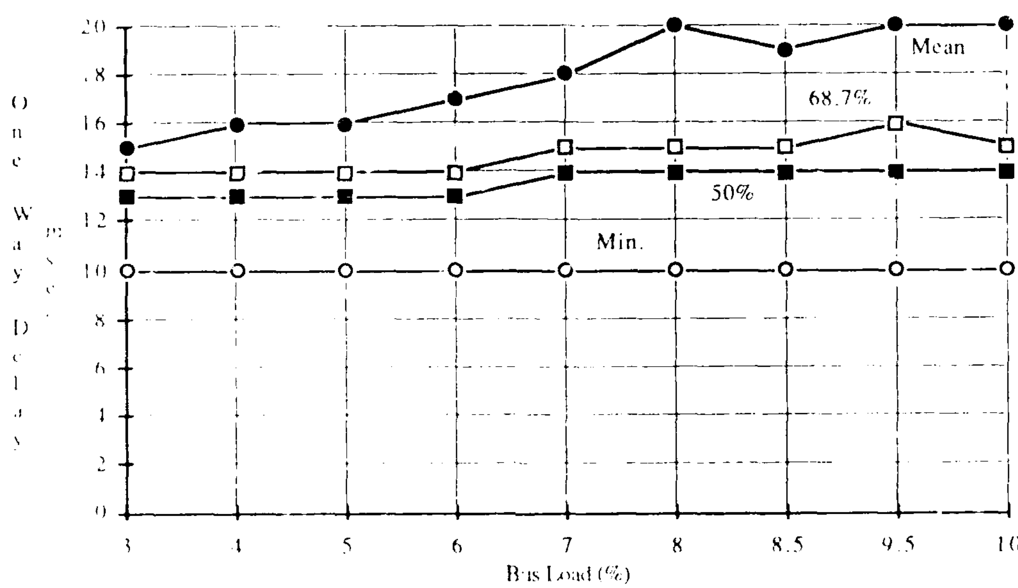
Test 17

Background Traffic (vc's)	Unbridged Bus Load (%)	Mean Delay (msec)	Min. Delay (msec)	<=50% Delay (msec)	<=68.7% Delay (msec)	<=99.9% Delay (msec)	Max. Delay (msec)	Total Characters Transferred
16	3	15	10	13	14	85	123	1002
32	4	16	10	13	14	103	217	1000
48	5	16	10	13	14	74	144	1003
64	6	17	10	13	14	127	188	1003
80	7	18	10	14	15	197	199	1001
96	8	20	10	14	15	230	962	1003
112	8.5	19	10	14	15	133	153	1004
128	9.5	20	10	14	16	157	247	1003
136	10	20	10	14	15	225	307	1002



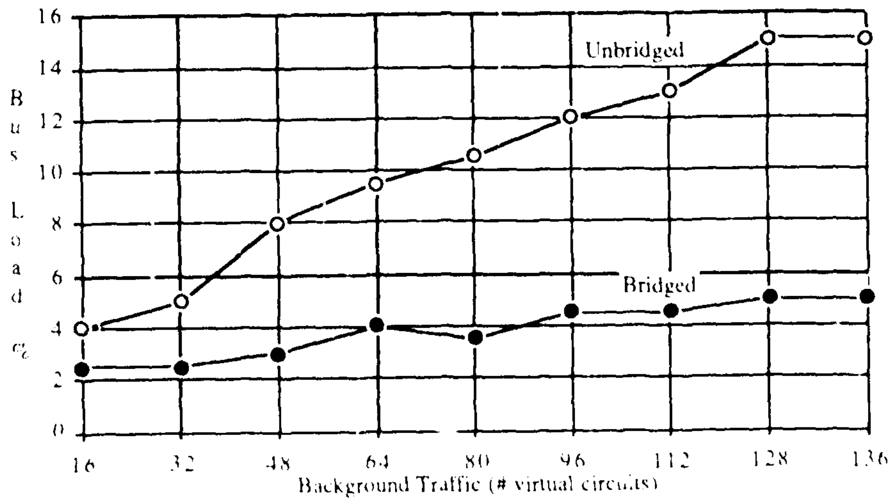
Test 17 (concluded)



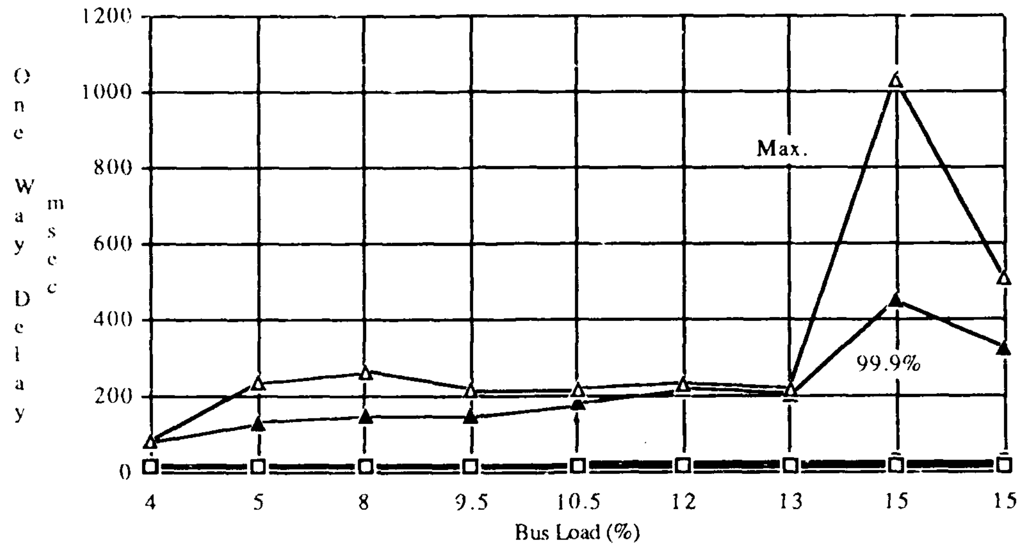


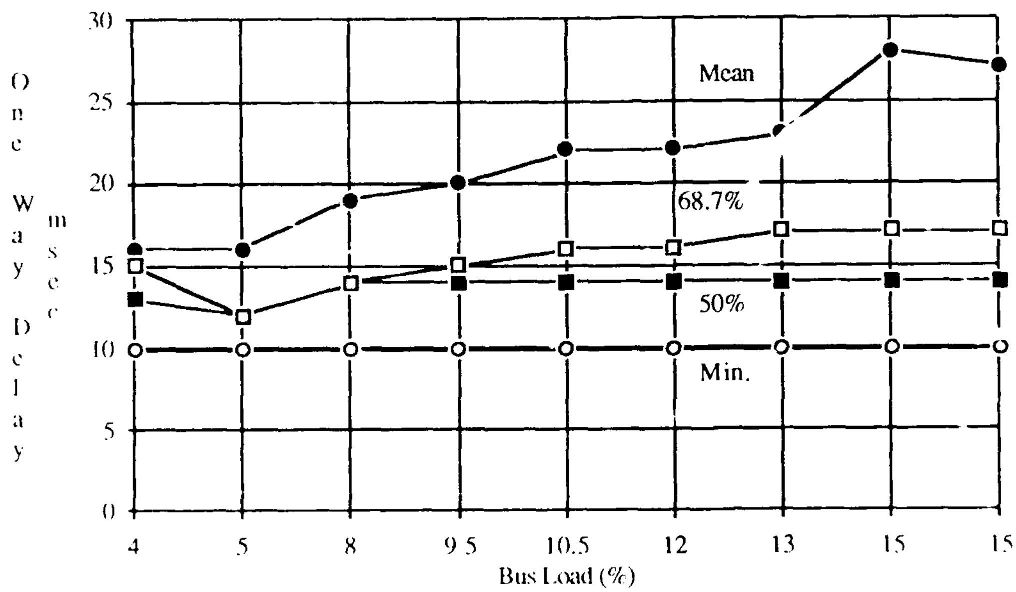
Test 18

Background Traffic (vc's)	25% Bridged Bus Load (%)	5% Unbridge Bus Load (%)	Mean Delay (msec)	Min. Delay (msec)	<=50% Delay (msec)	<=68.7% Delay (msec)	<=99.9% Delay (msec)	Max. Delay (msec)	Total Characters Transferred
16	2.5	4	16	10	13	15	78	84	1002
32	2.5	5	16	10	12	12	130	233	1004
48	3	8	19	10	14	14	145	264	1003
64	4	9.5	20	10	14	15	147	214	1004
80	3.5	10.5	22	10	14	16	178	215	1004
96	4.5	12	22	10	14	16	216	230	1002
112	4.5	13	23	10	14	17	200	215	1003
128	5	15	28	10	14	17	447	1026	1003
136	5	15	27	10	14	17	321	510	1004



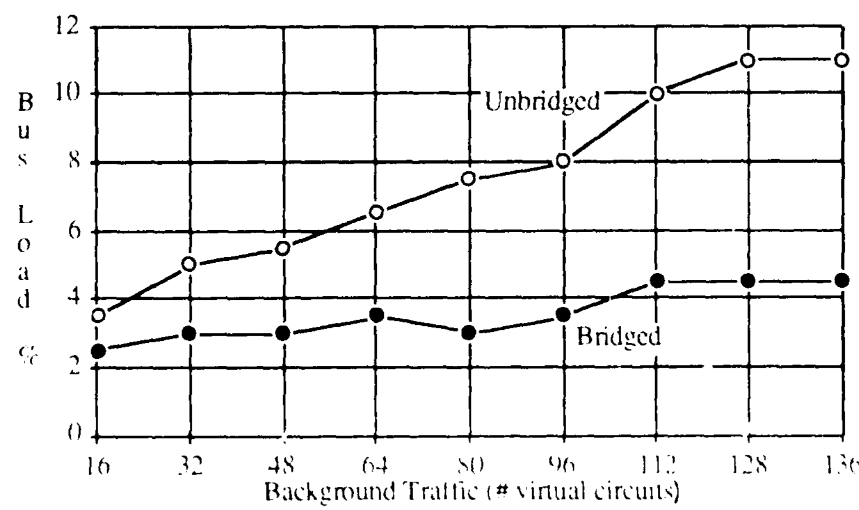
Test 18 (concluded)



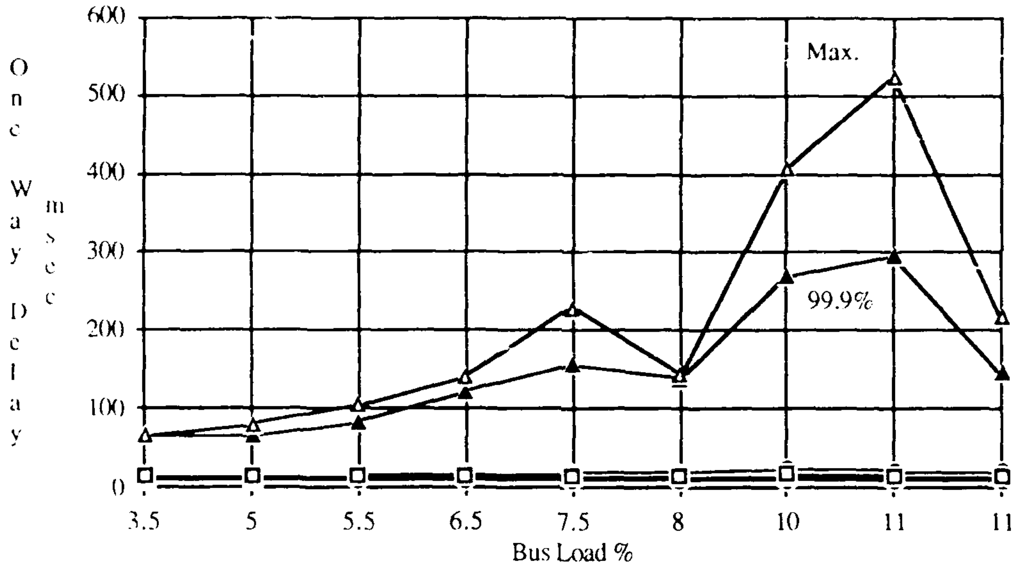


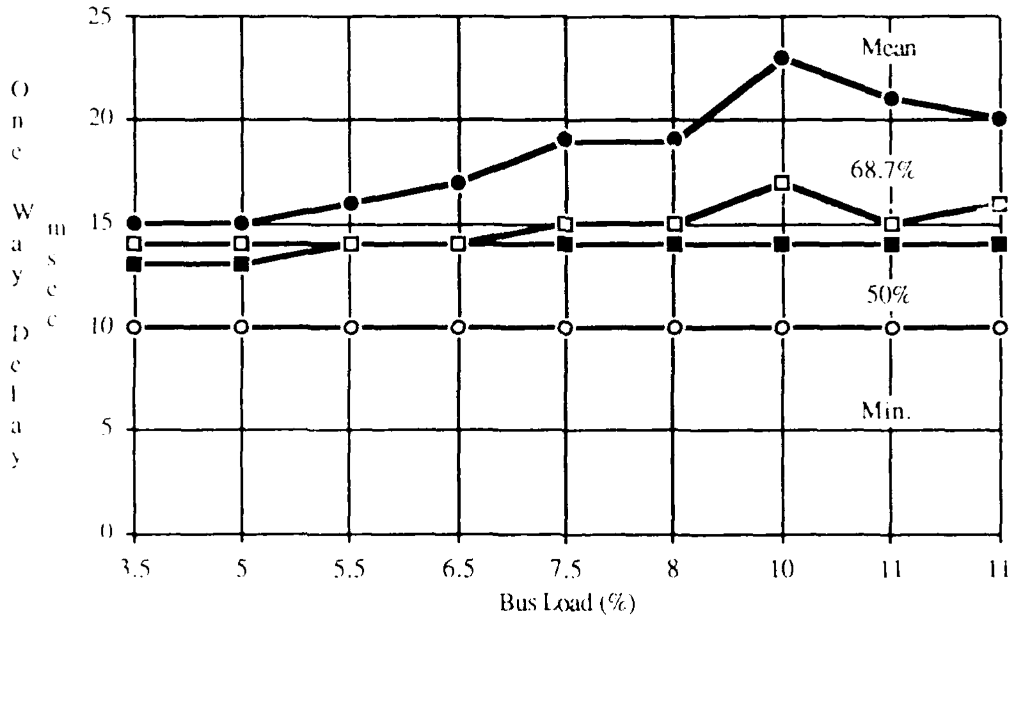
Test 19

Background Traffic (vc's)	25% Bridged Bus Load (%)	75% Unbridged Bus Load (%)	Mean Delay (msec)	Min. Delay (msec)	<=50% Delay (msec)	<=68.7% Delay (msec)	<=99.9% Delay (msec)	Max. Delay (msec)	Total Characters Transferred
16	2.5	3.5	15	10	13	14	65	66	1004
32	3	5	15	10	13	14	65	80	1004
48	3	5.5	16	10	14	14	84	105	1002
64	3.5	6.5	17	10	14	14	122	142	1004
80	3	7.5	19	10	14	15	157	230	1003
96	3.5	8	19	10	14	15	139	143	1003
112	4.5	10	23	10	14	17	269	405	1005
128	4.5	11	21	10	14	15	296	523	1005
136	4.5	11	20	10	14	16	147	220	1001



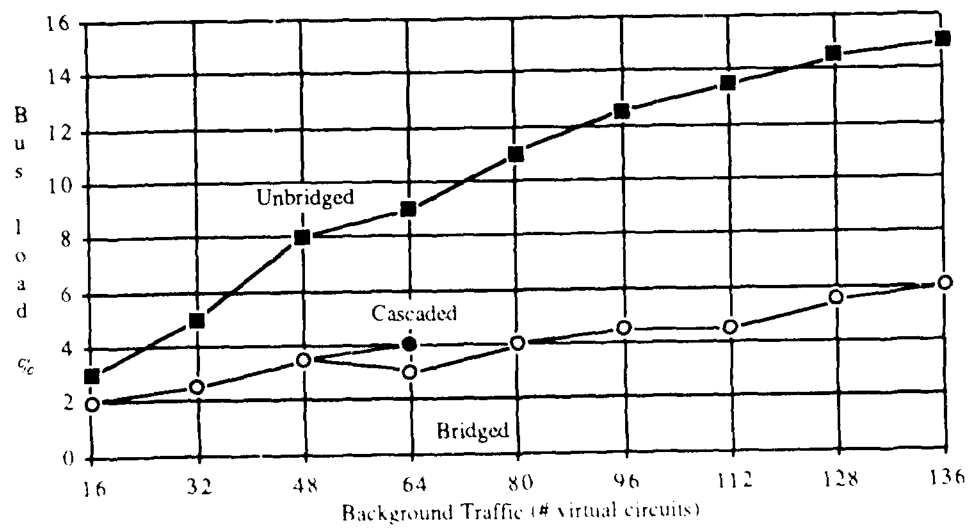
Test 19 (concluded)



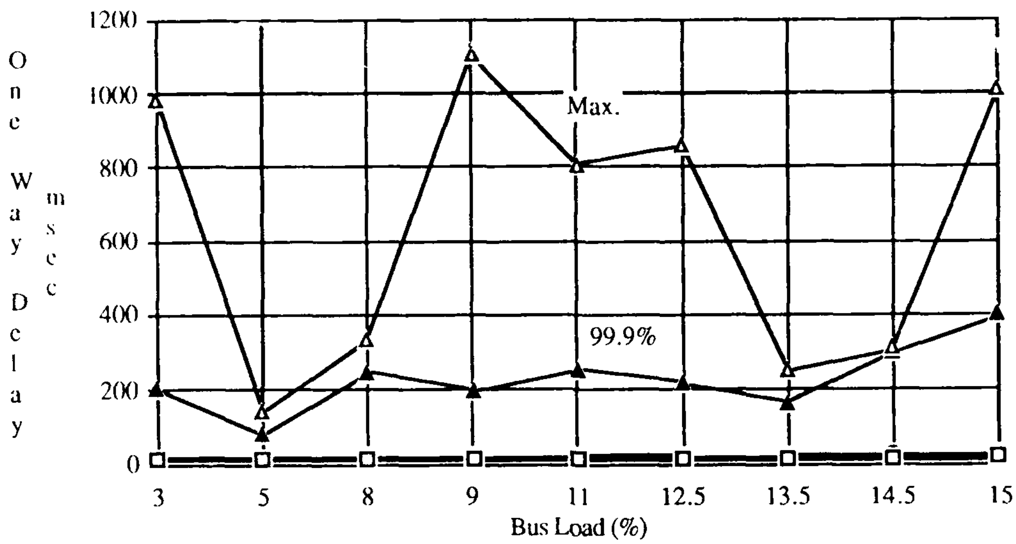


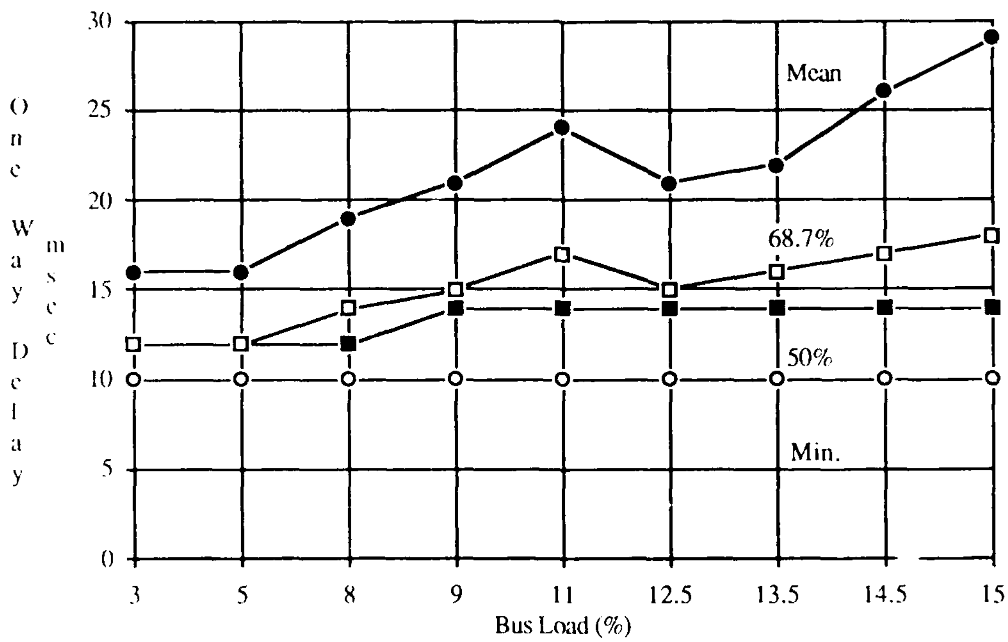
Test 20

Background Traffic (vc's)	Cascade Load (%)	25% Load Bridged (%)	75% Load Local (%)	Mean Delay (msec)	Min. Delay (msec)	<=50% Delay (msec)	<=68.7% Delay (msec)	<=99.9% Delay (msec)	Max. Delay (msec)	Total Characters Transferred
16	2	2	3	16	10	12	12	205	984	999
32	2.5	2.5	5	16	10	12	12	79	143	1003
48	3.5	3.5	8	19	10	12	14	247	336	1002
64	4	3	9	21	10	14	15	198	1106	1004
80	4	4	11	24	10	14	17	254	807	1003
96	4.5	4.5	12.5	21	10	14	15	216	859	1002
112	4.5	4.5	13.5	22	10	14	16	167	250	1003
128	5.5	5.5	14.5	26	10	14	17	301	311	1002
136	6	6	15	29	10	14	18	401	1013	1001



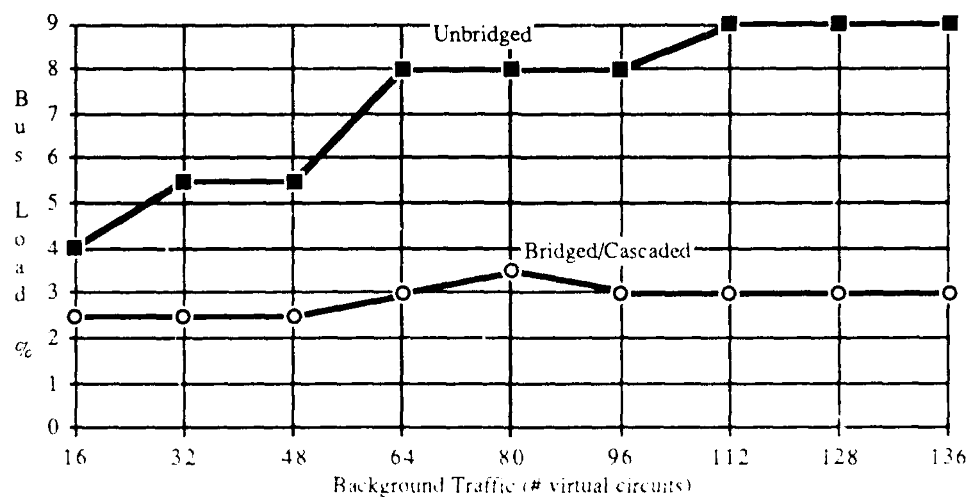
Test 20 (concluded)



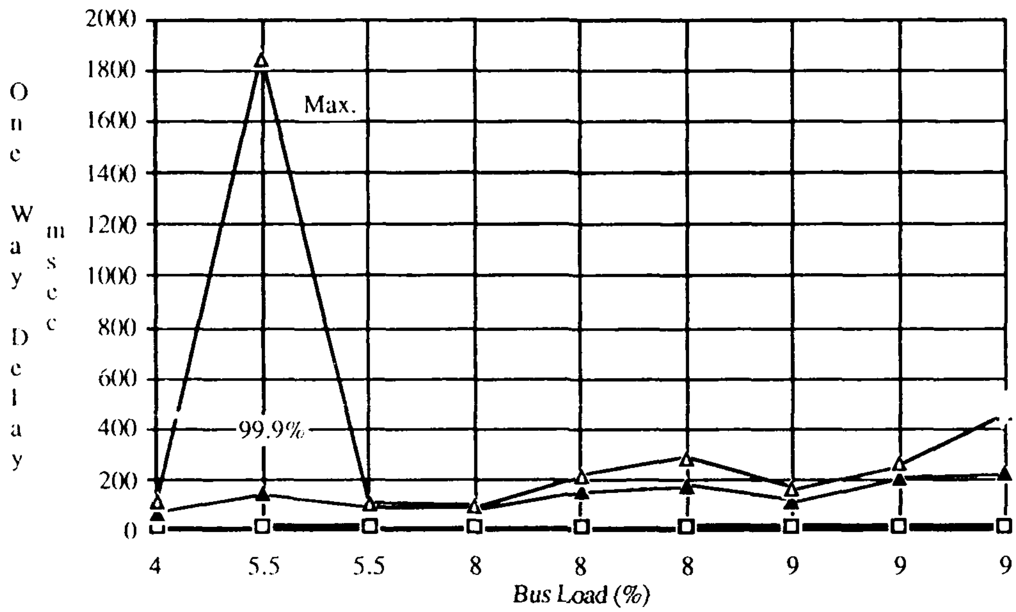


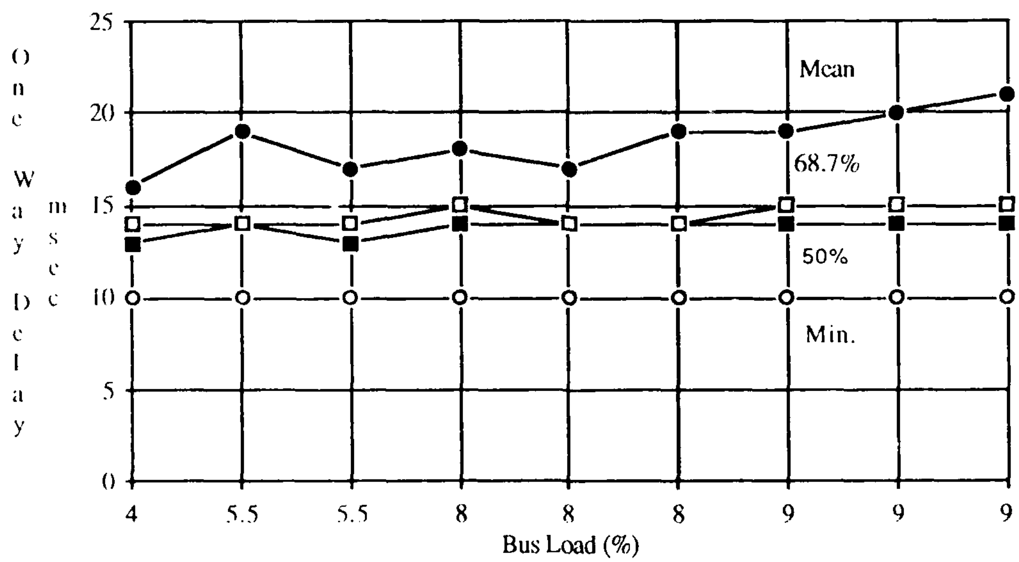
Test 21

Background Traffic (vc's)	Cascade Load (%)	25% Load Bridged (%)	75% Load Local (%)	Mean Delay (msec)	Min. Delay (msec)	<=50% Delay (msec)	<=68.7% Delay (msec)	<=99.9% Delay (msec)	Max. Delay (msec)	Total Characters Transferred
16	2.5	2.5	4	16	10	13	14	70	114	1002
32	2.5	2.5	5.5	19	10	14	14	146	1840	1001
48	2.5	2.5	5.5	17	10	13	14	95	111	1000
64	3	3	8	18	10	14	15	85	95	1004
80	3.5	3.5	8	17	10	14	14	155	218	1003
96	3	3	8	19	10	14	14	178	290	1003
112	3	3	9	19	10	14	15	114	165	1003
128	3	3	9	20	10	14	15	208	261	1000
136	3	3	9	21	10	14	15	223	466	1000



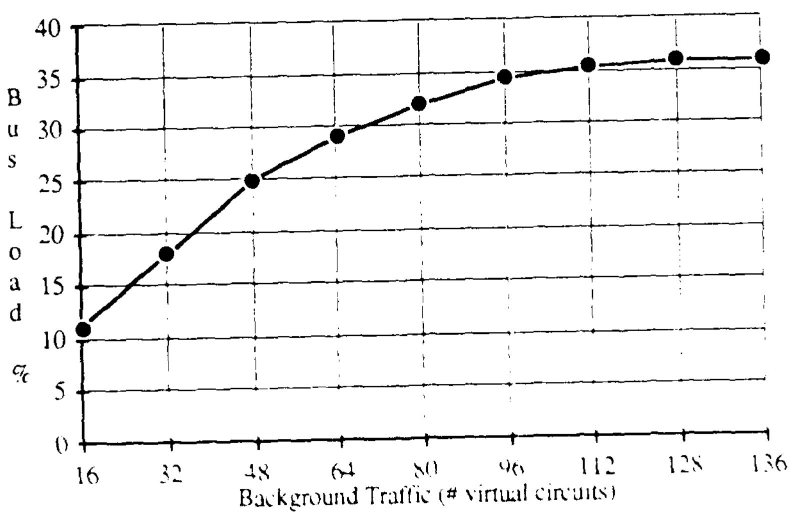
Test 21 (concluded)



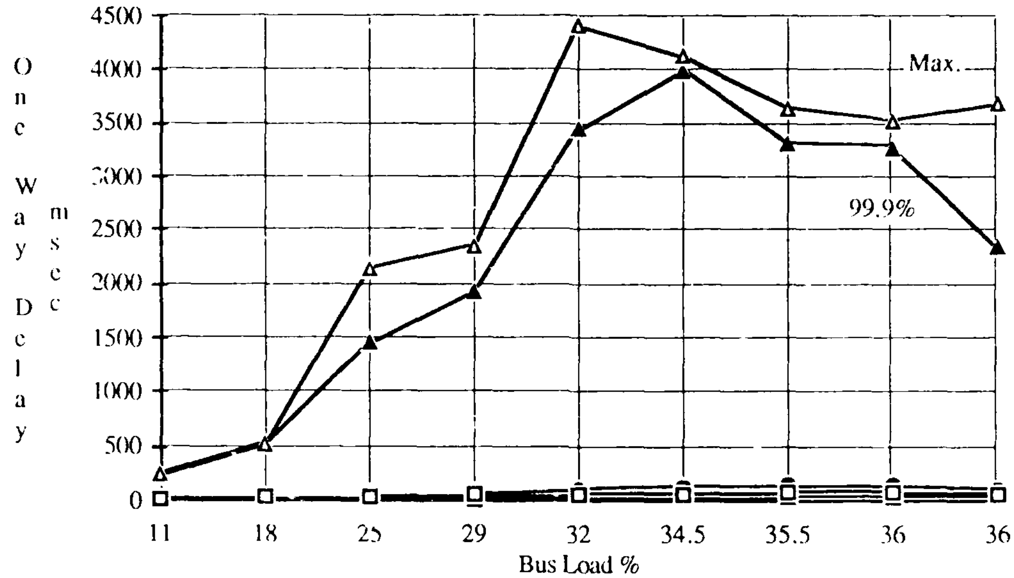


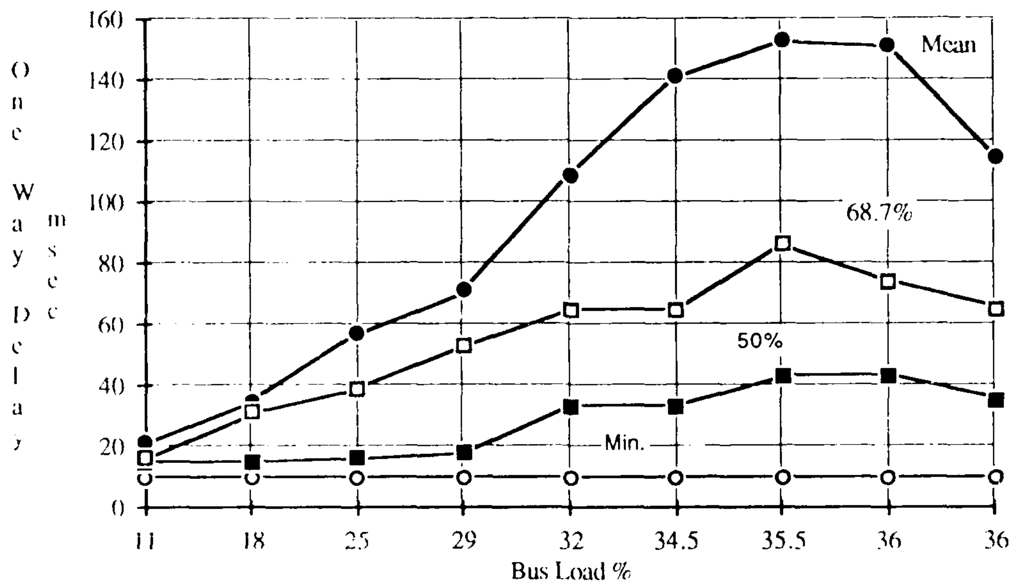
Test 22

Background Traffic (vc's)	Bus Load (%)	Mean Delay (msec)	Min. Delay (msec)	<=50% Delay (msec)	<=68.7% Delay (msec)	<=99.9% Delay (msec)	Max. Delay (msec)	Total Characters Transferred
16	11	21	10	15	16	230	250	1003
32	18	35	10	15	31	530	538	1005
48	25	57	10	16	39	1461	2149	1003
64	29	71	10	18	53	1940	2365	1005
80	32	109	10	33	65	3457	4419	1000
96	34.5	141	10	33	65	4008	4131	1004
112	35.5	153	10	43	86	3323	3655	1002
128	36	151	10	43	74	3279	3537	1002
136	36	115	10	35	65	2356	3697	1005



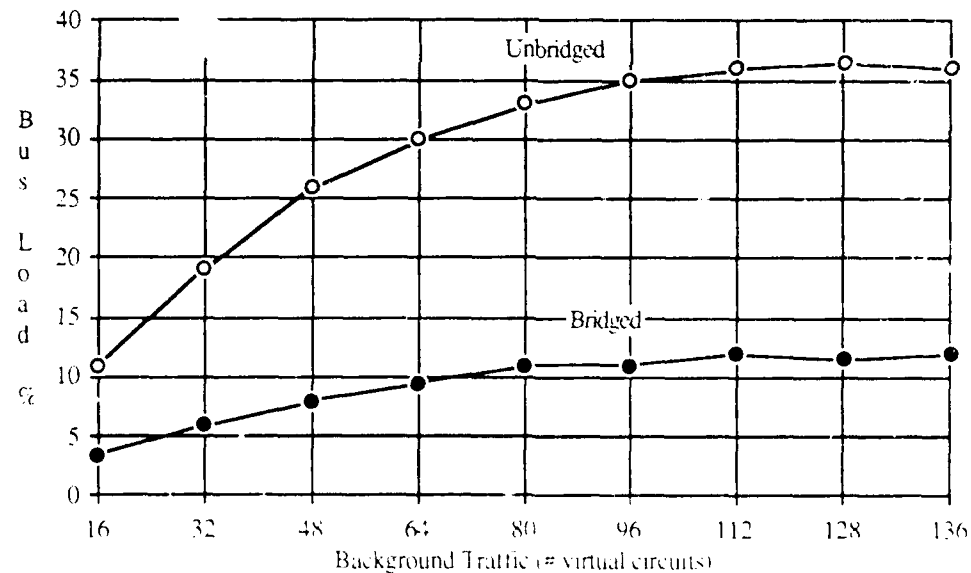
Test 22 (concluded)



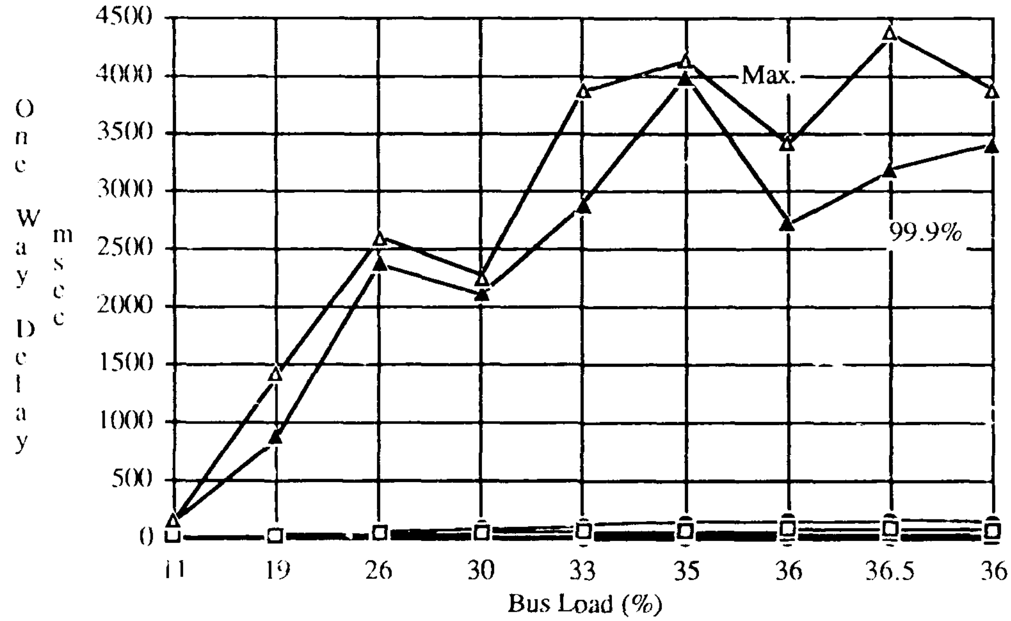


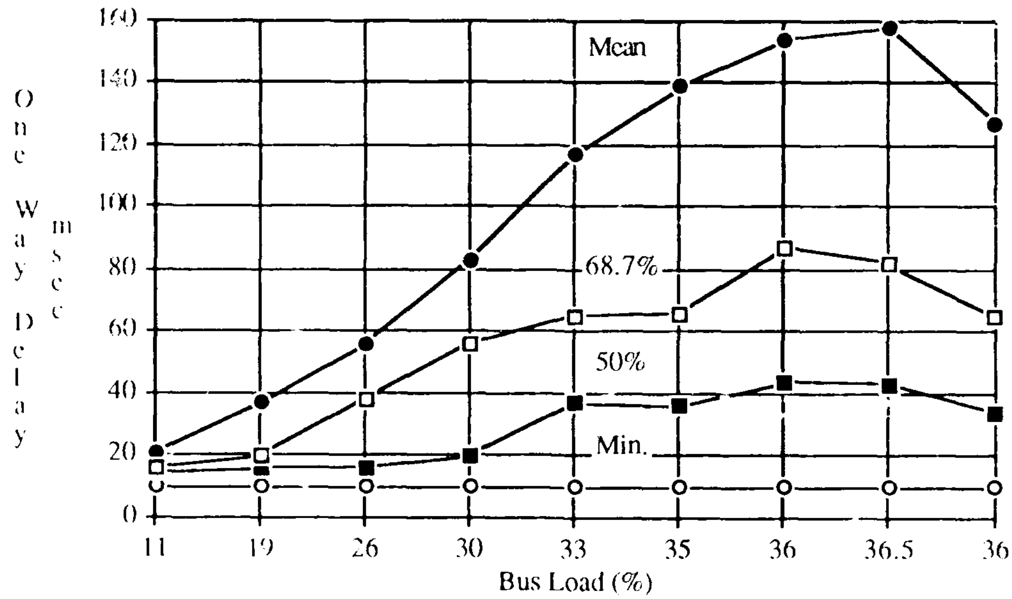
Test 23

Background Traffic (vc's)	25% Bridged Bus Load (%)	75% Unbridged Bus Load (%)	Mean Delay (msec)	Min. Delay (msec)	<=50% Delay (msec)	<=68.7% Delay (msec)	<=99.9% Delay (msec)	Max. Delay (msec)	Total Characters Transferred
16	3.5	11	21	10	15	16	152	155	1001
32	6	19	37	10	16	20	869	1416	1004
48	8	26	56	10	16	38	2375	2595	1003
64	9.5	30	83	10	20	56	2107	2252	1004
80	11	33	117	10	37	65	2886	3869	1004
96	11	35	139	10	36	66	3994	4138	1043
112	12	36	154	10	44	87	2713	3419	1003
128	11.5	36.5	158	10	43	82	3188	4373	1005
136	12	36	127	10	34	65	3406	3881	1001



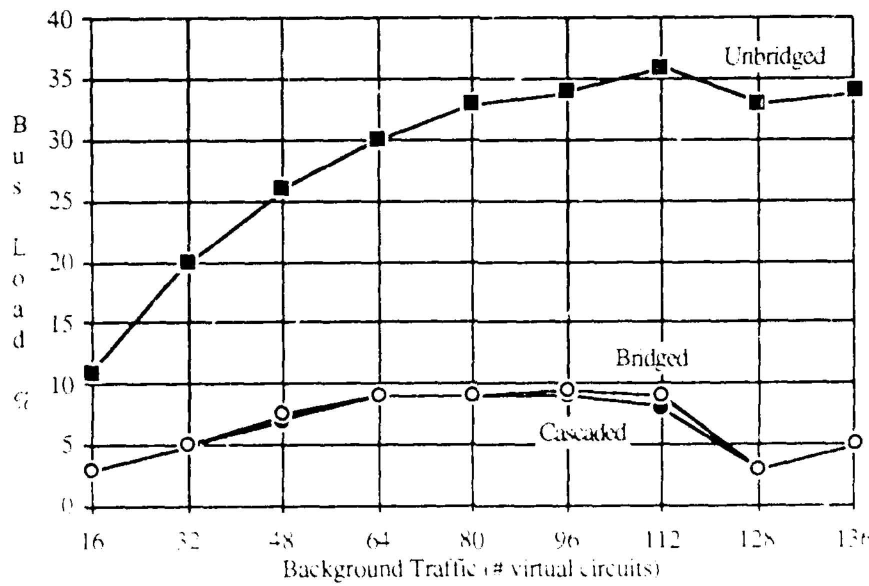
Test 23 (concluded)



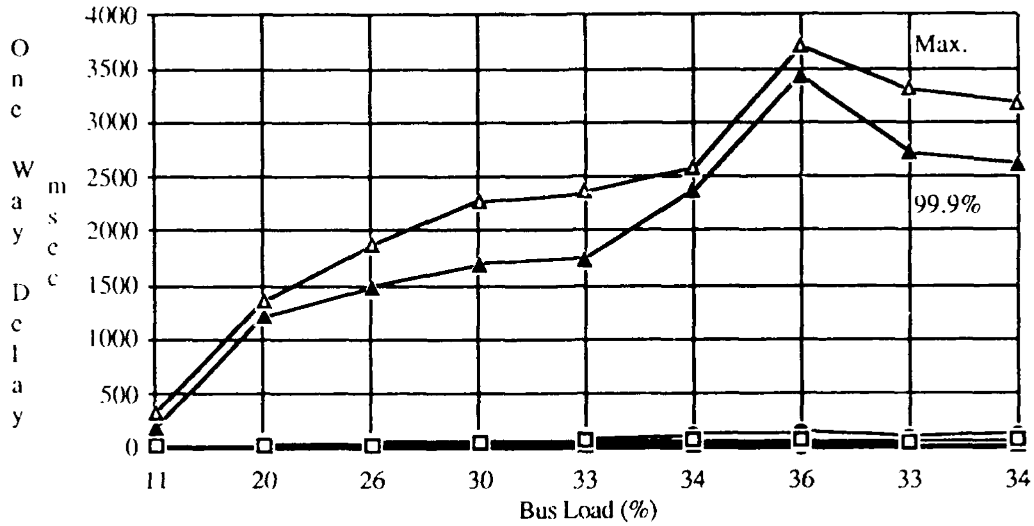


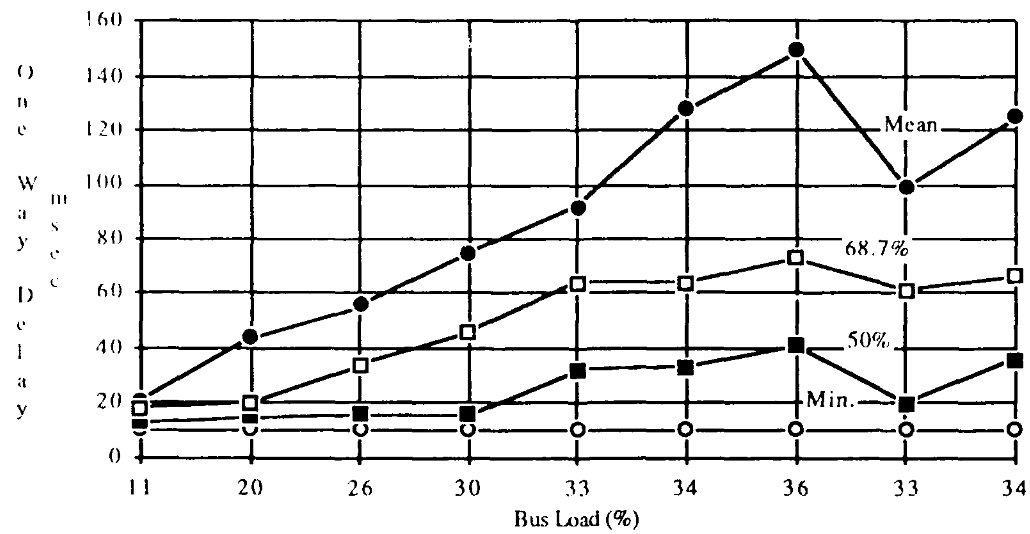
Test 24

Background Traffic (vc's)	Cascade Load (%)	25% Load Bridged (%)	75% Load Local (%)	Mean Delay (msec)	Min. Delay (msec)	<=50% Delay (msec)	<=68.7% Delay (msec)	<=99.9% Delay (msec)	Max. Delay (msec)	Total Characters Transferred
16	3	3	11	21	10	13	18	185	332	1003
32	5	5	20	44	10	15	20	1213	1357	1002
48	7	7.5	26	56	10	16	34	1485	1870	1005
64	9	9	30	75	10	16	46	1695	2273	1004
80	9	9	33	92	10	32	64	1743	2365	1003
96	9	9.5	34	128	10	33	64	2361	2584	1000
112	8	9	36	149	10	41	73	3426	3705	1001
128	3	3	33	99	10	20	61	2726	3300	1006
136	5	5	34	125	10	36	66	2611	3169	1003



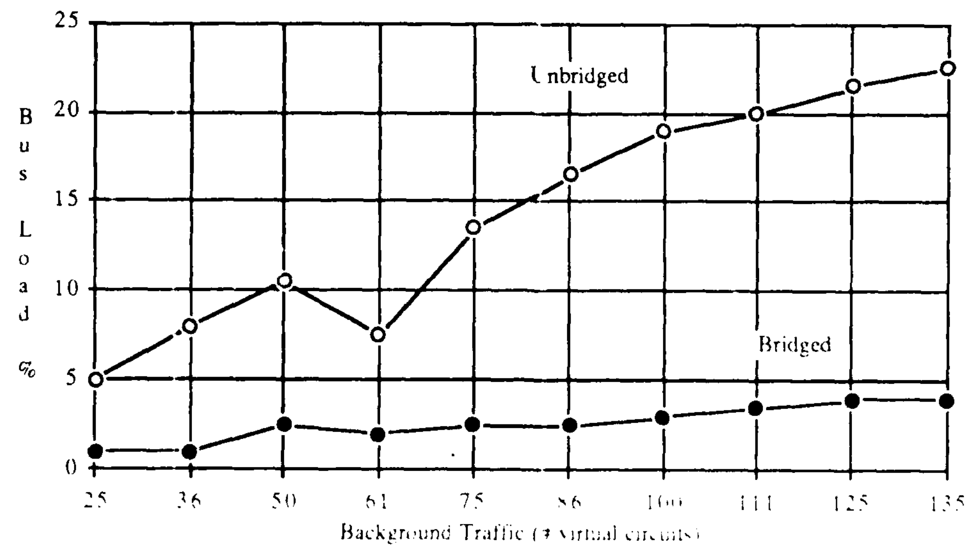
Test 24 (concluded)



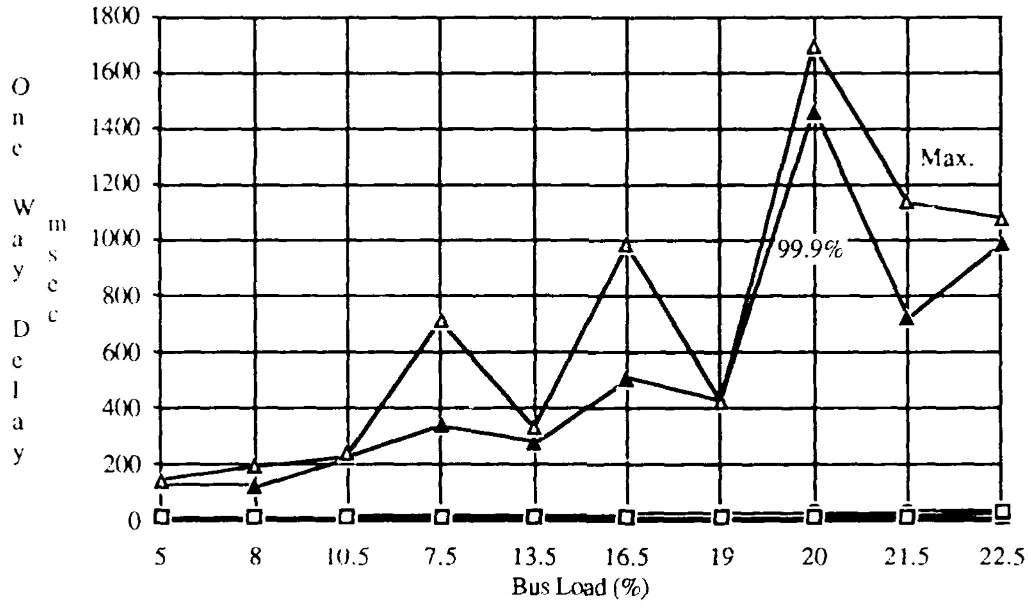


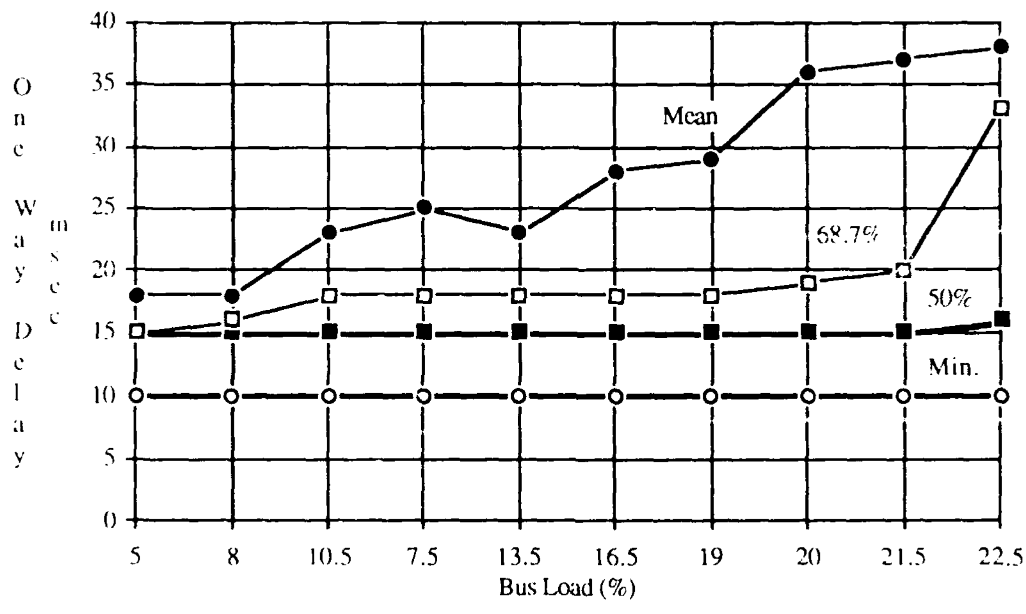
Test 25

Background Traffic (vc's)	18.75% Bridged Load (%)	81.25% Unbridged Load (%)	Mean Delay (msec)	Min. Delay (msec)	<=50% Delay (msec)	<=68.7% Delay (msec)	<=99.9% Delay (msec)	Max. Delay (msec)	Total Characters Transferred
25	1	5	18	10	15	15	131	147	1003
36	1	8	18	10	15	16	124	198	1004
50	2.5	10.5	23	10	15	18	227	240	1002
61	2	7.5	25	10	15	18	343	714	1005
75	2.5	13.5	23	10	15	18	280	338	1005
86	2.5	16.5	28	10	15	18	510	983	1004
100	3	19	29	10	15	18	424	424	1002
111	3.5	20	36	10	15	19	1459	1691	1005
125	4	21.5	37	10	15	20	724	1138	1005
135	4	22.5	38	10	16	33	987	1076	1003



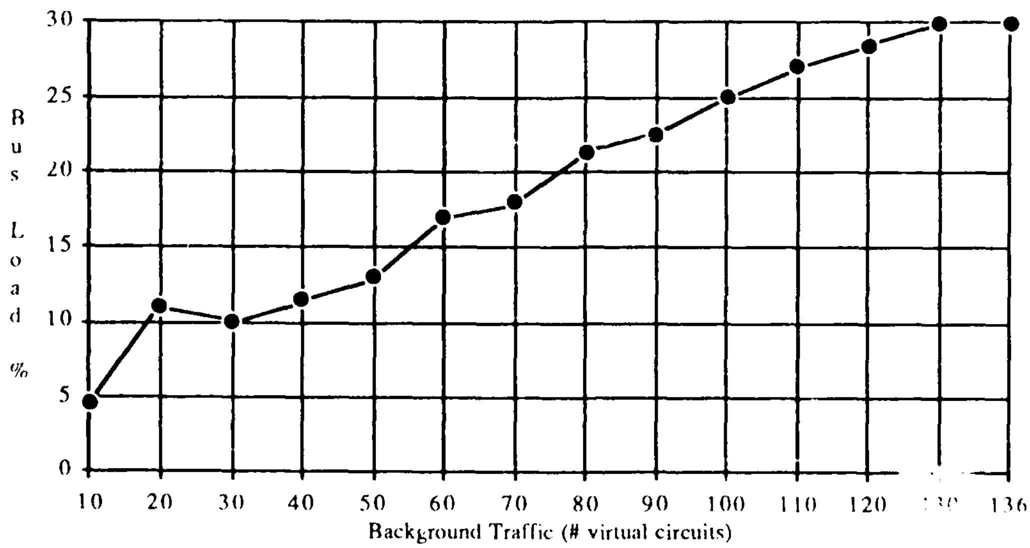
Test 25 (concluded)



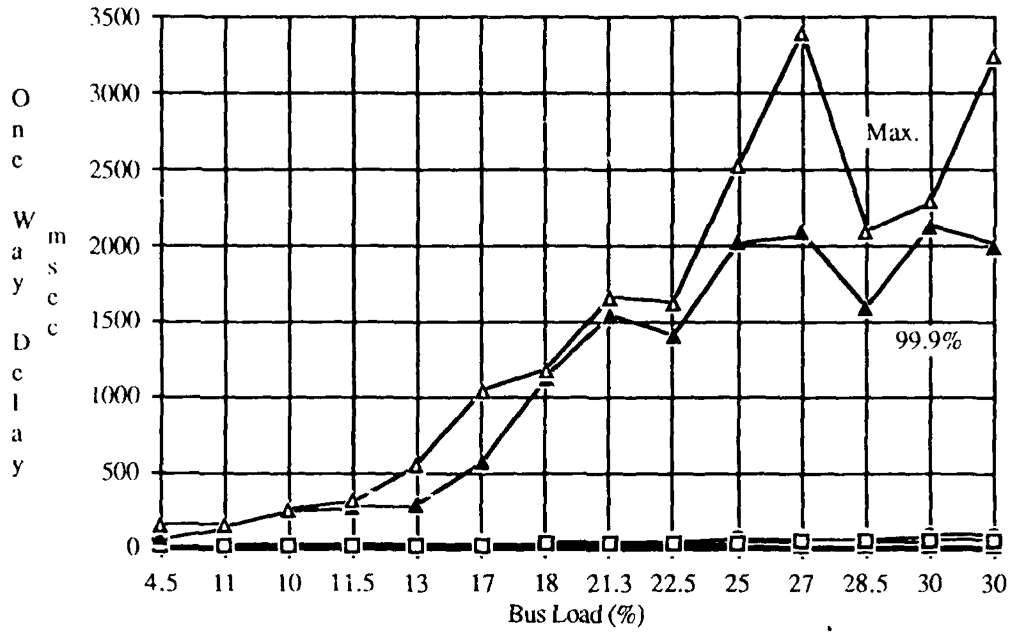


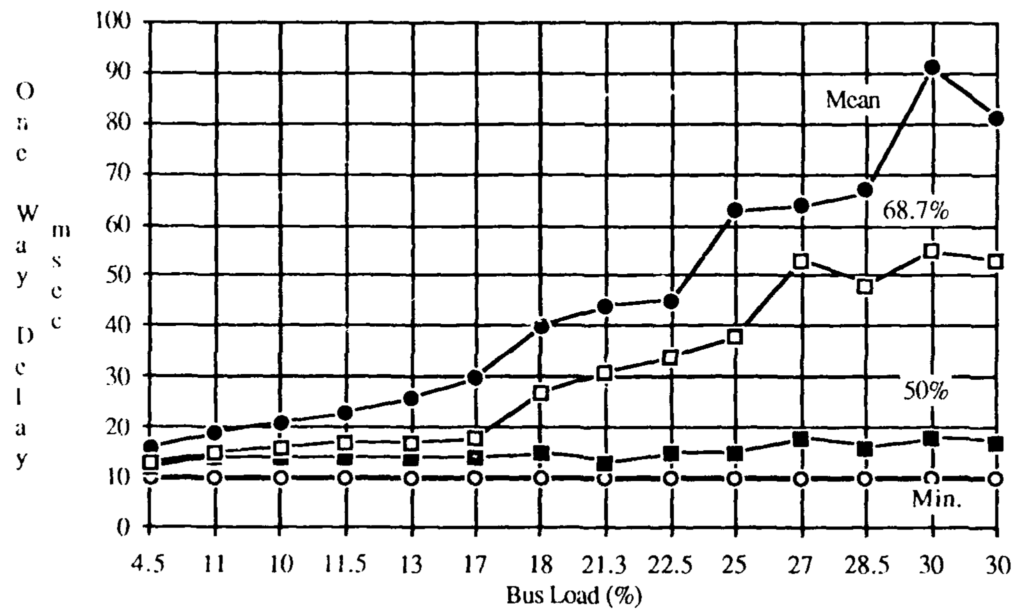
Test 26

Background Traffic (vc's)	Unbridged Bus Load (%)	Mean Delay (msec)	Min. Delay (msec)	<=50% Delay (msec)	<=68.7% Delay (msec)	<=99.9% Delay (msec)	Max. Delay (msec)	Total Characters Transferred
10	4.5	16	10	12	13	69	156	1004
20	11	19	10	14	15	140	152	1003
30	10	21	10	14	16	245	259	1004
40	11.5	23	10	14	17	276	320	1004
50	13	26	10	14	17	292	559	1005
60	17	30	10	14	18	568	1040	1003
70	18	40	10	15	27	1126	1179	1004
80	21.3	44	10	13	31	1544	1660	1005
90	22.5	45	10	15	34	1406	1622	1004
100	25	63	10	15	38	2021	2531	1004
110	27	64	10	18	53	2085	3404	1007
120	28.5	67	10	16	48	1597	2095	1002
130	30	91	10	18	55	2133	2295	1002
136	30	81	10	17	53	2001	3241	1005



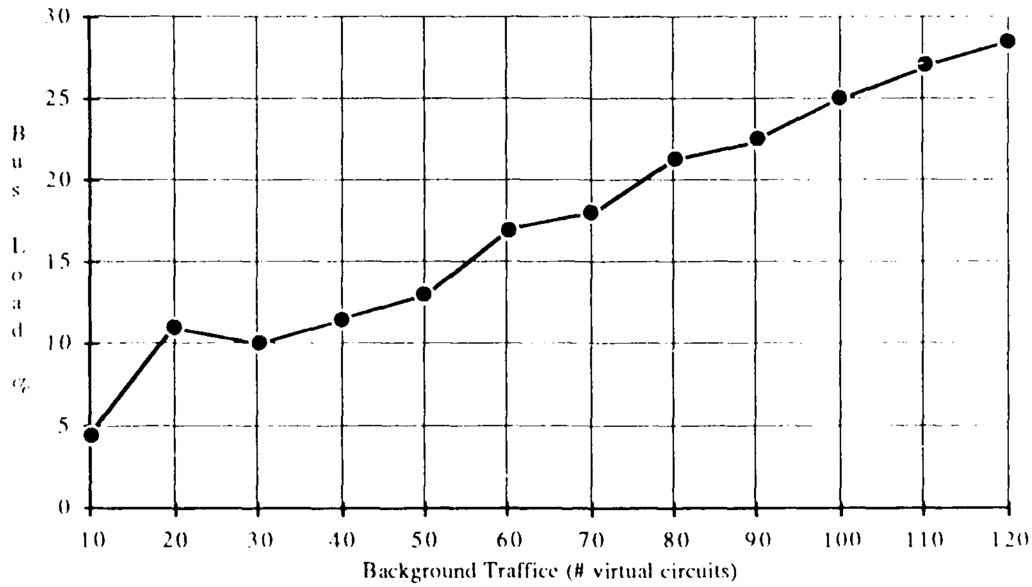
Test 26 (concluded)



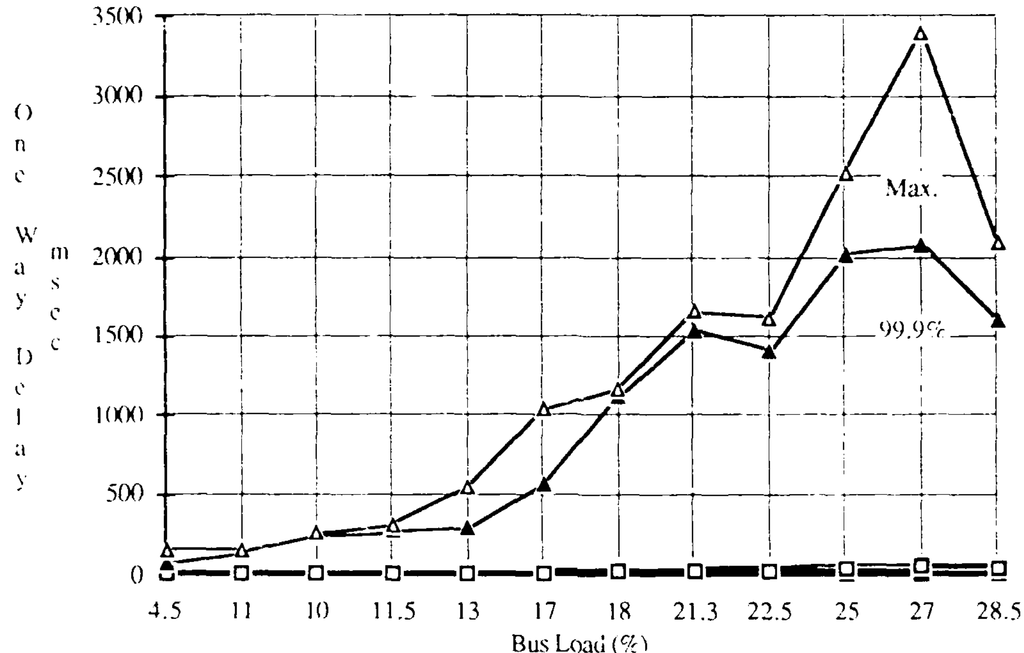


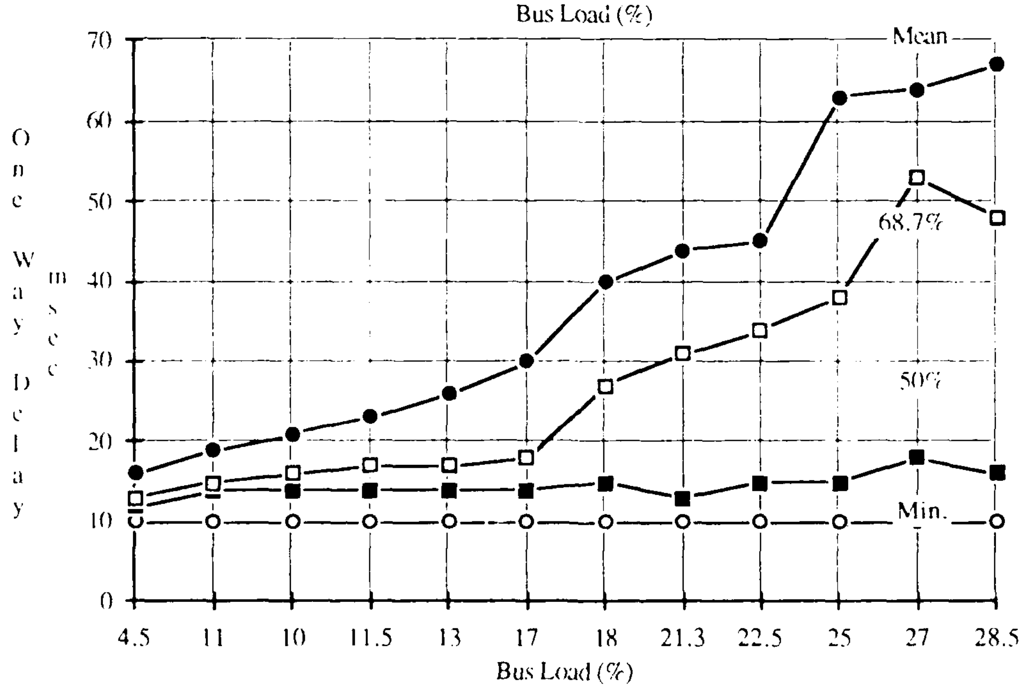
Test 27

Background Traffic (vc's)	Unbridged Bus Load (%)	Mean Delay (msec)	Min. Delay (msec)	<=50% Delay (msec)	<=68.7% Delay (msec)	<=99.9% Delay (msec)	Max. Delay (msec)	Total Characters Transferred
10	4.5	16	10	12	13	69	156	1004
20	11	19	10	14	15	140	152	1003
30	10	21	10	14	16	245	259	1004
40	11.5	23	10	14	17	276	320	1004
50	13	26	10	14	17	292	559	1005
60	17	30	10	14	18	568	1040	1003
70	18	40	10	15	27	1126	1179	1004
80	21.3	44	10	13	31	1544	1660	1005
90	22.5	45	10	15	34	1406	1622	1004
100	25	63	10	15	38	2021	2531	1004
110	27	64	10	18	53	2085	3404	1007
120	28.5	67	10	16	48	1597	2095	1002
130	30	91	10	18	55	2133	2295	1002
136	30	81	10	17	53	2001	3241	1005



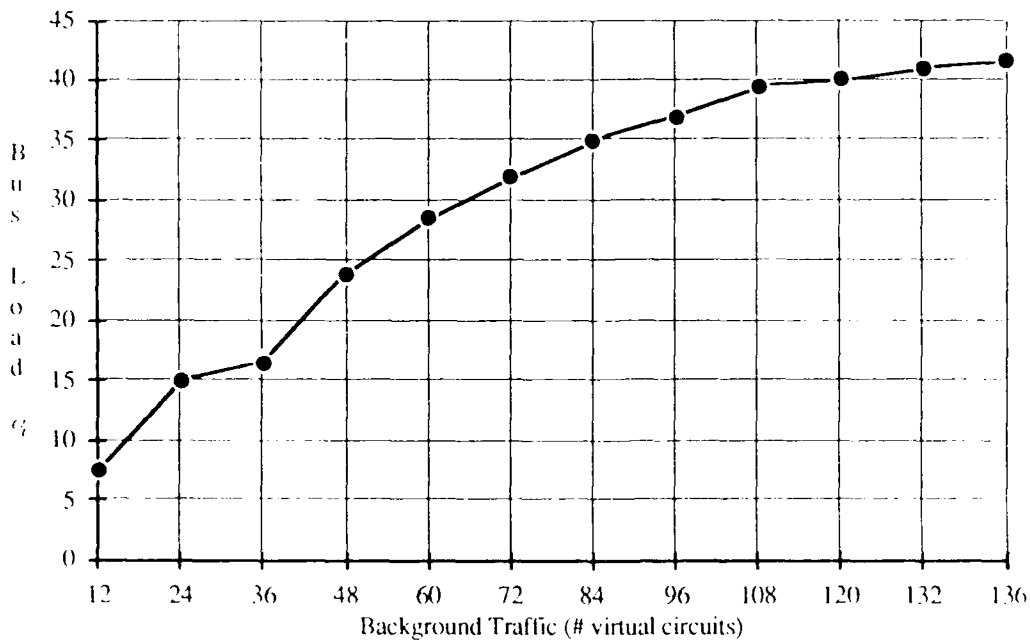
Test 27 (concluded)



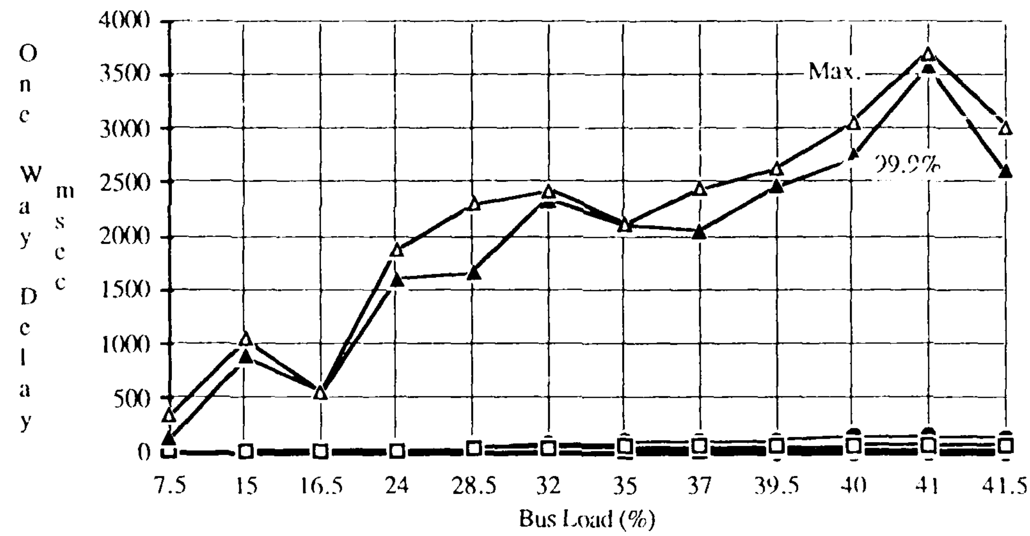


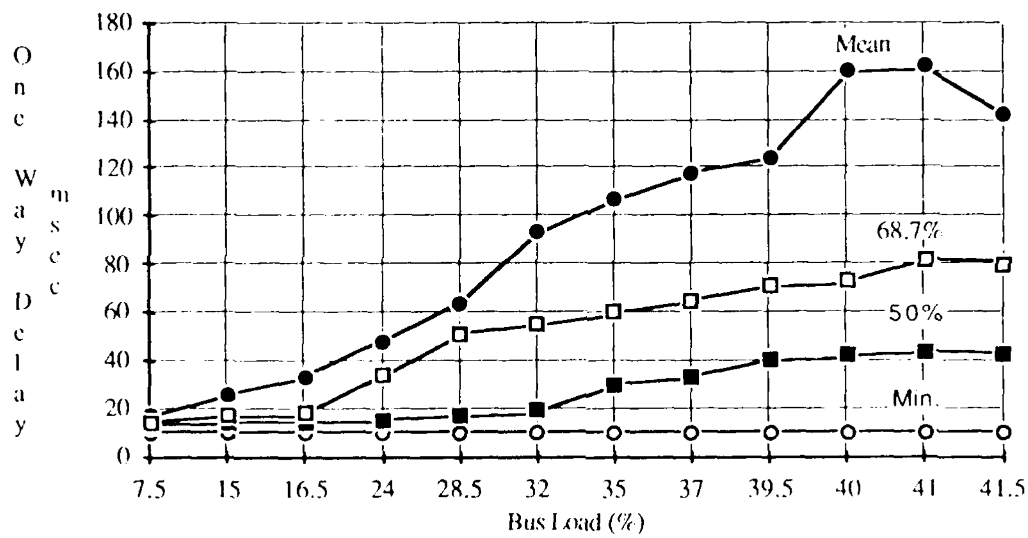
Test 28

Background Traffic (vc's)	Unbridged Bus Load (%)	Mean Delay (msec)	Min. Delay (msec)	<=50% Delay (msec)	<=68.7% Delay (msec)	<=99.9% Delay (msec)	Max. Delay (msec)	Total Characters Transferred
12	7.5	17	10	13	14	135	354	1005
24	15	26	10	14	17	887	1056	1005
36	16.5	33	10	14	18	560	576	1003
48	24	48	10	15	34	1607	1884	1001
60	28.5	64	10	17	51	1676	2301	1006
72	32	93	10	19	55	2345	2439	1004
84	35	107	10	30	60	2107	2117	1002
96	37	118	10	33	65	2055	2447	1006
108	39.5	124	10	40	71	2470	2649	1003
120	40	160	10	42	73	2748	3067	1002
132	41	162	10	44	82	3581	3704	1003
136	41.5	142	10	42	80	2614	3024	1003



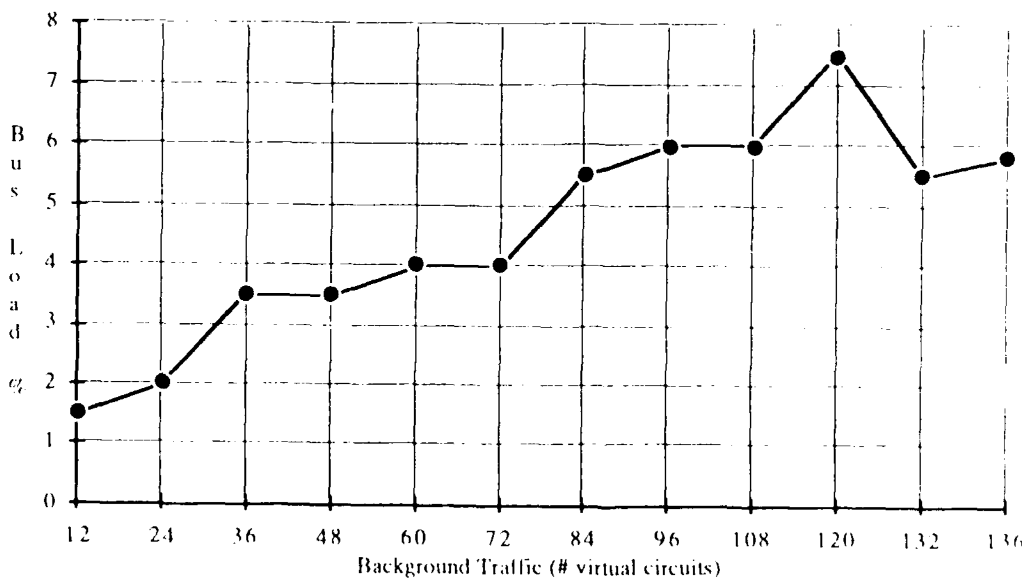
Test 28 (concluded)



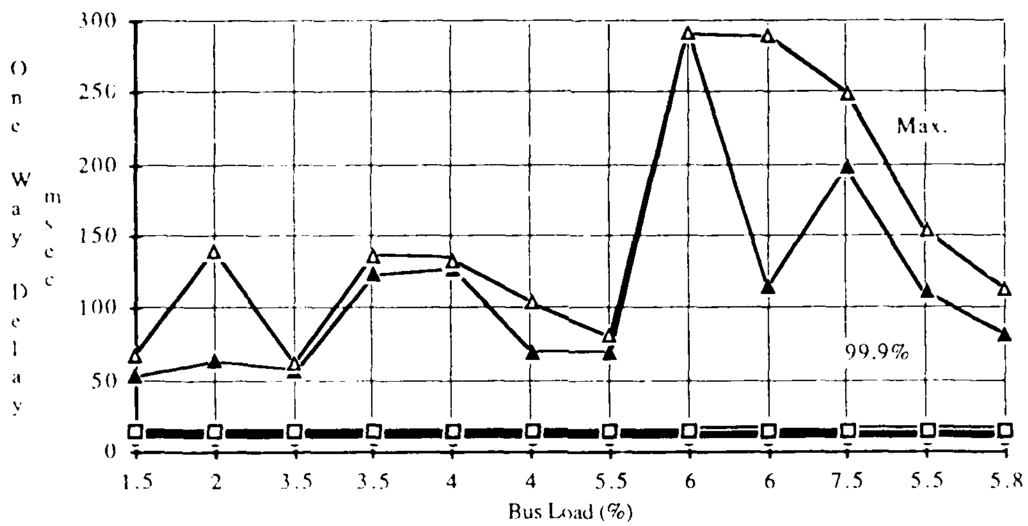


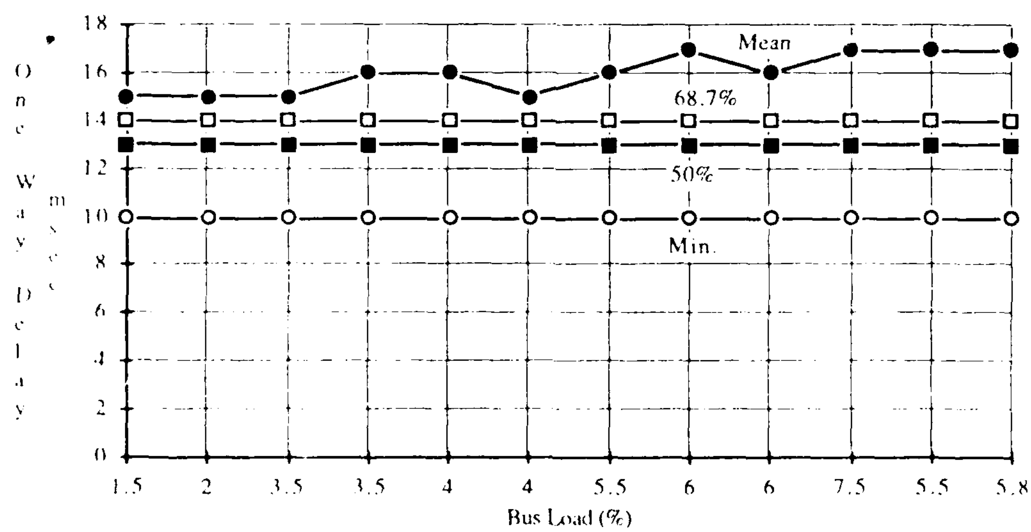
Test 29

Background Traffic (vc's)	Unbridged Bus Load (%)	Mean Delay (msec)	Min. Delay (msec)	<=50% Delay (msec)	<=68.7% Delay (msec)	<=99.9% Delay (msec)	Max. Delay (msec)	Total Characters Transferred
12	1.5	15	10	13	14	53	68	1005
24	2	15	10	13	14	64	140	1005
36	3.5	15	10	13	14	57	63	1004
48	3.5	16	10	13	14	124	137	1002
60	4	16	10	13	14	128	134	1003
72	4	15	10	13	14	70	104	1004
84	5.5	16	10	13	14	69	81	1003
96	6	17	10	13	14	292	292	1004
108	6	16	10	13	14	116	290	1004
120	7.5	17	10	13	14	198	250	1003
132	5.5	17	10	13	14	111	154	1004
136	5.8	17	10	13	14	82	114	1004



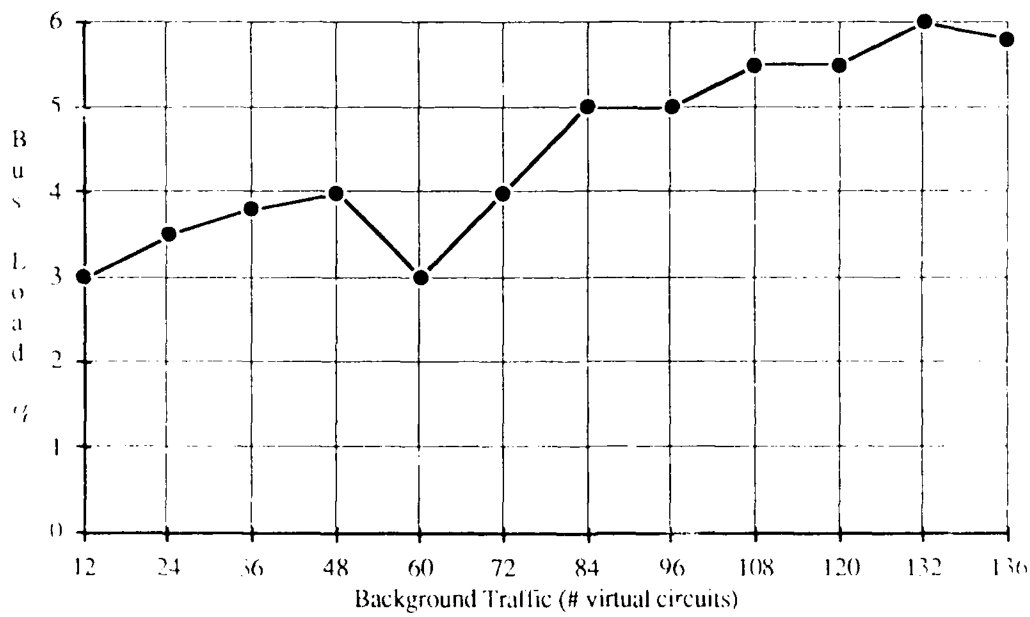
Test 29 (concluded)



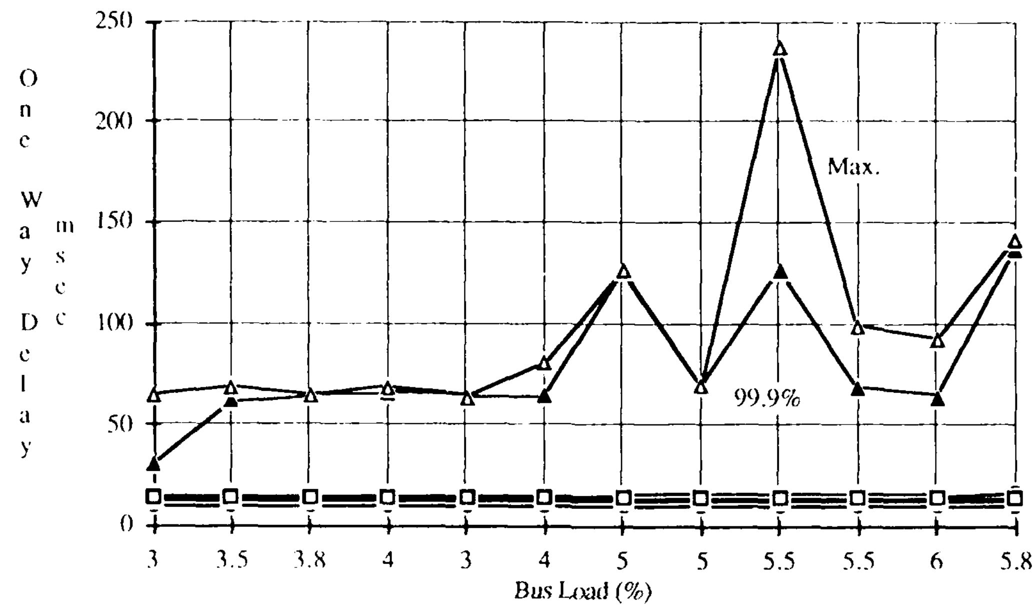


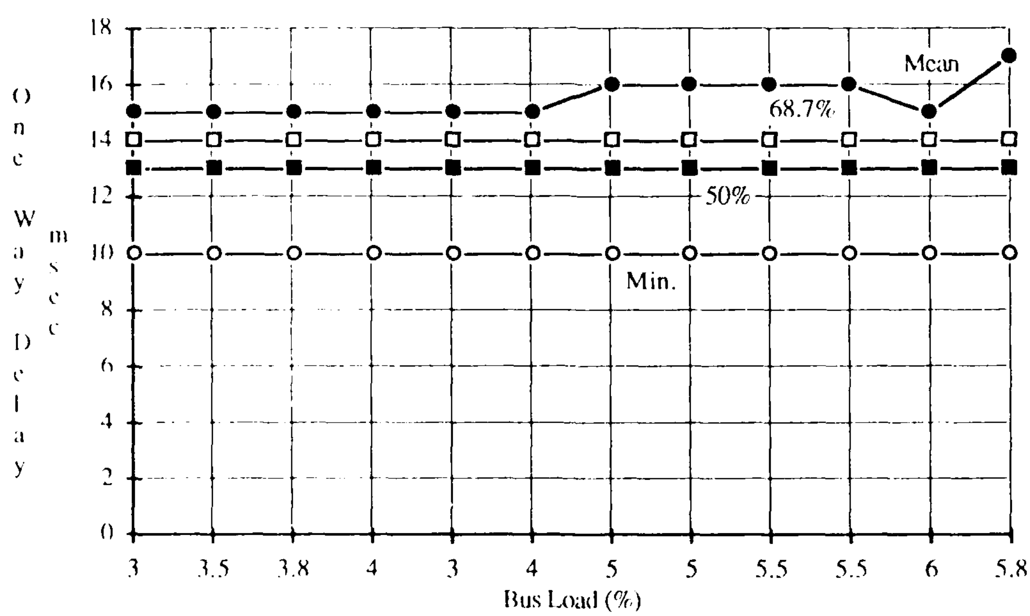
Test 30

Background Traffic (vc's)	Unbridged Bus Load %)	Mean Delay (msec)	Min. Delay (msec)	<=50% Delay (msec)	<=68.7% Delay (msec)	<=99.9% Delay (msec)	Max. Delay (msec)	Total Characters Transferred
12	3	15	10	13	14	31	65	1003
24	3.5	15	10	13	14	62	69	1004
36	3.8	15	10	13	14	65	65	1004
48	4	15	10	13	14	66	69	1004
60	3	15	10	13	14	64	64	1004
72	4	15	10	13	14	65	81	1003
84	5	16	10	13	14	126	127	1003
96	5	16	10	13	14	70	70	1004
108	5.5	16	10	13	14	127	237	1004
120	5.5	16	10	13	14	69	99	1002
132	6	15	10	13	14	64	92	1002
136	5.8	17	10	13	14	137	142	1003



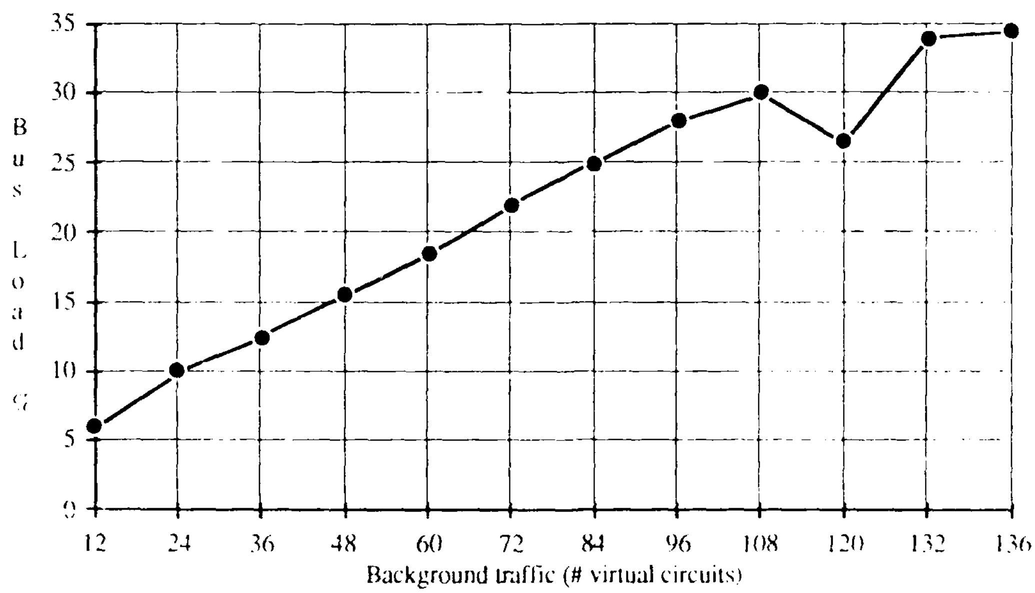
Test 30 (concluded)



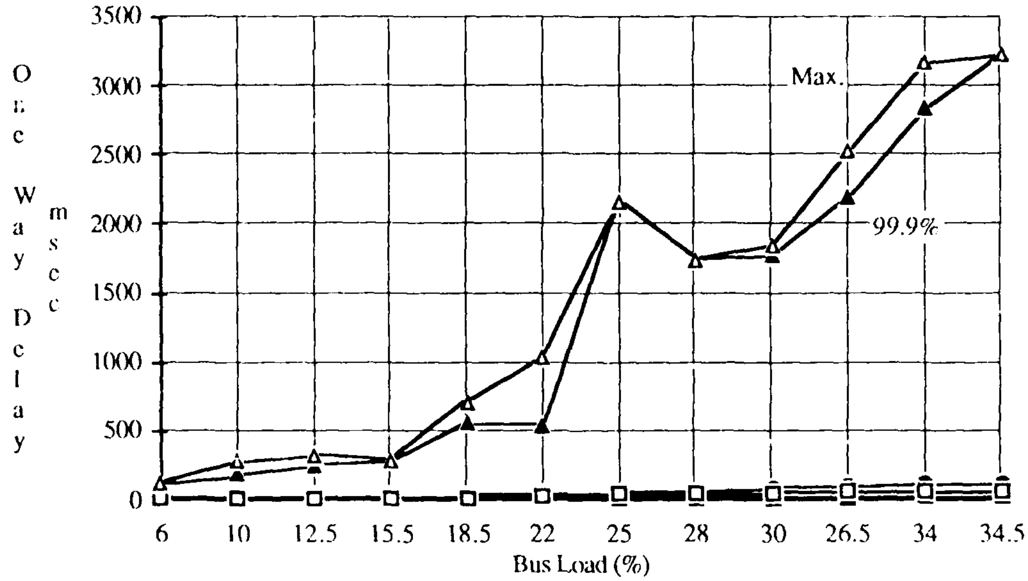


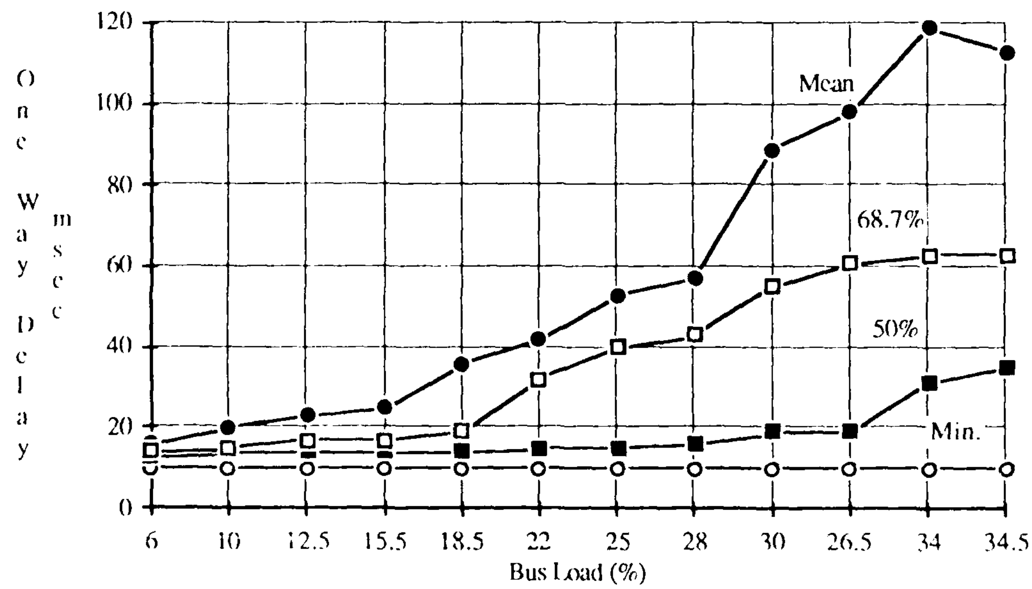
Test 31

Background Traffic (vc's)	Unbridged Bus Load (%)	Mean Delay (msec)	Min. Delay (msec)	<=50% Delay (msec)	<=68.7% Delay (msec)	<=99.9% Delay (msec)	Max. Delay (msec)	Total Characters Transferred
12	6	16	10	13	14	117	126	1003
24	10	20	10	14	15	188	279	1001
36	12.5	23	10	14	17	258	326	1003
48	15.5	25	10	14	17	280	288	1004
60	18.5	36	10	14	19	557	713	1006
72	22	42	10	15	32	541	1043	1003
84	25	53	10	15	40	2166	2166	1001
96	28	57	10	16	43	1743	1746	1002
108	30	89	10	19	55	1773	1851	1004
120	26.5	98	10	19	61	2197	2530	1004
132	34	119	10	31	63	2839	3170	1002
136	34.5	113	10	35	63	3238	3238	1000



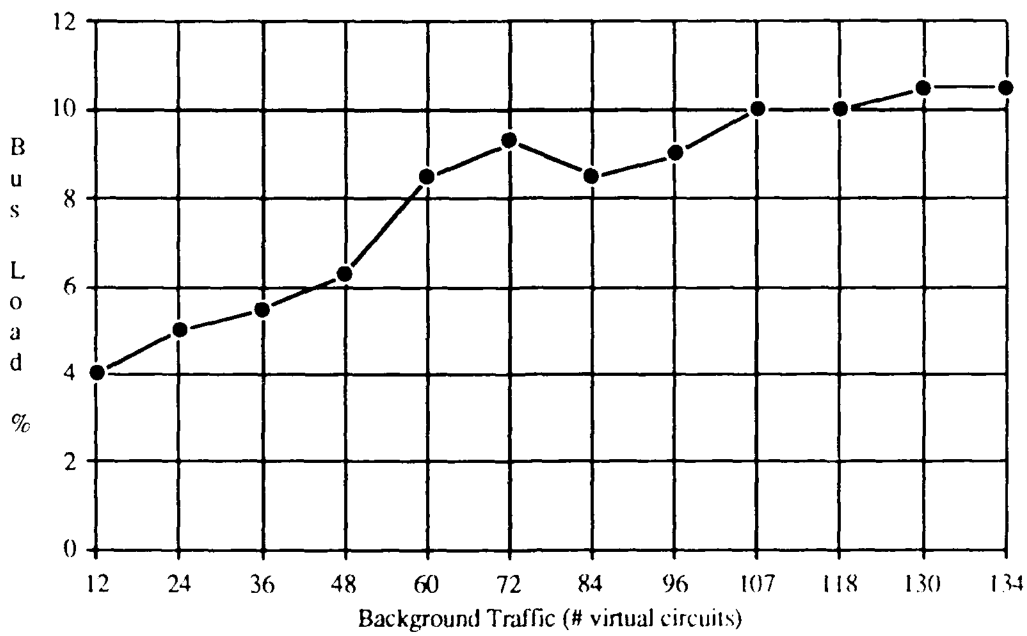
Test 31 (concluded)



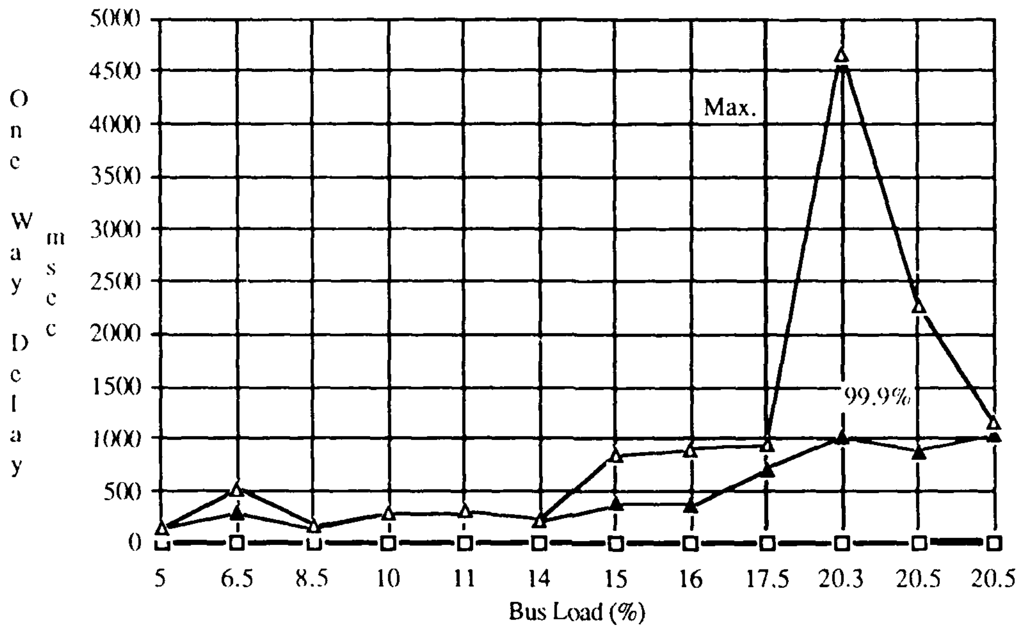


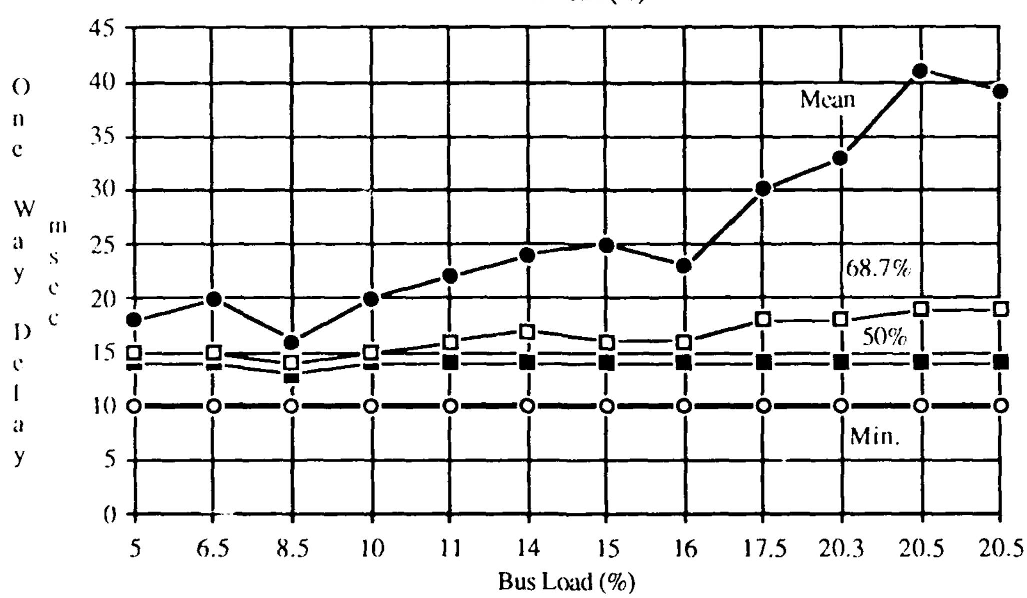
Test 32

Background Traffic (vc's)	Unbridged Bus Load (%)	Mean Delay (msec)	Min. Delay (msec)	<=50% Delay (msec)	<=68.7% Delay (msec)	<=99.9% Delay (msec)	Max. Delay (msec)	Total Characters Transferred
19	5	18	10	14	15	137	145	1004
29	6.5	20	10	14	15	289	526	1004
38	8.5	16	10	13	14	143	167	1003
48	10	20	10	14	15	291	295	1003
62	11	22	10	14	16	310	316	1005
72	14	24	10	14	17	221	233	1004
83	15	25	10	14	16	384	846	1003
94	16	23	10	14	16	363	912	1004
105	17.5	30	10	14	18	715	940	1003
118	20.3	33	10	14	18	1015	4660	1003
128	20.5	41	10	14	19	886	2284	1001
134	20.5	39	10	14	19	1054	1159	1004



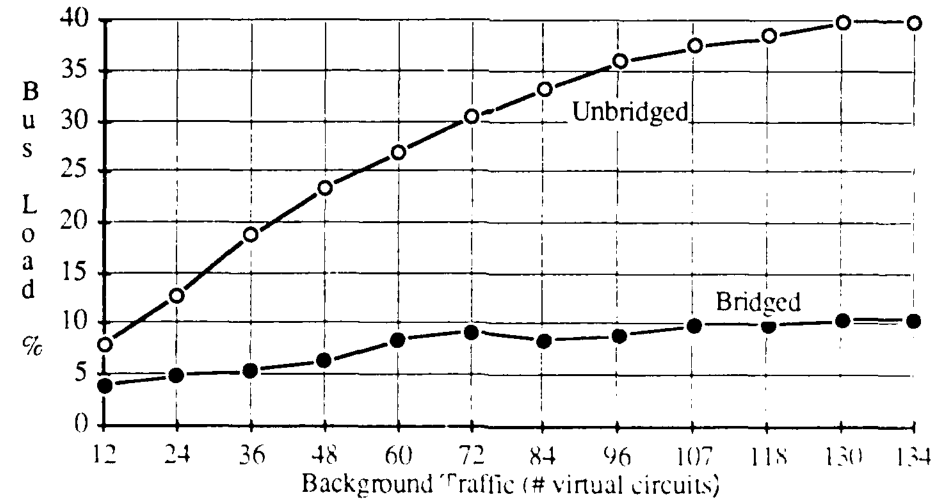
Test 32 (concluded)



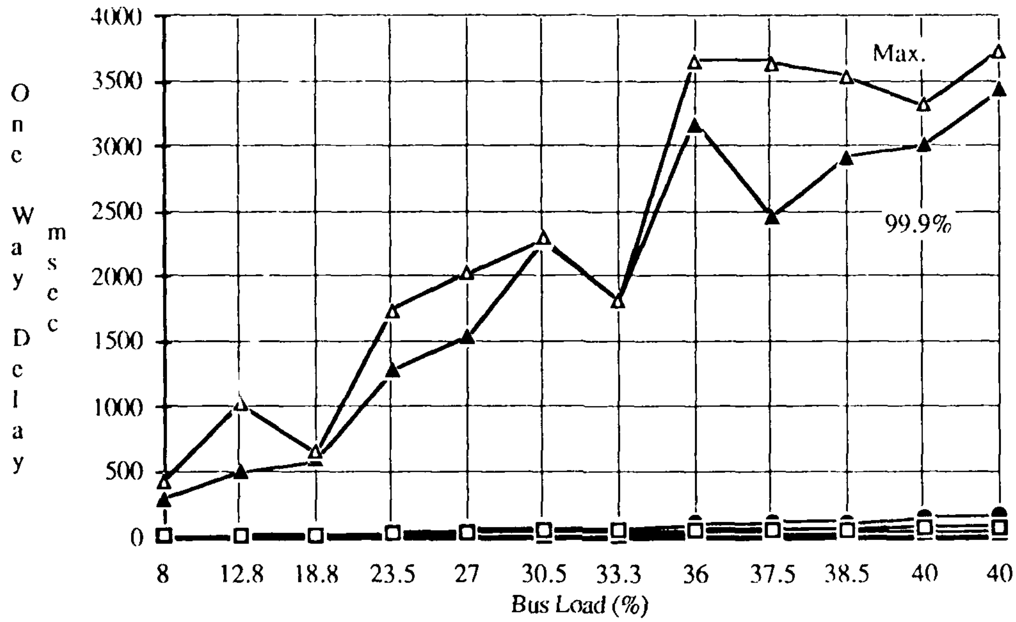


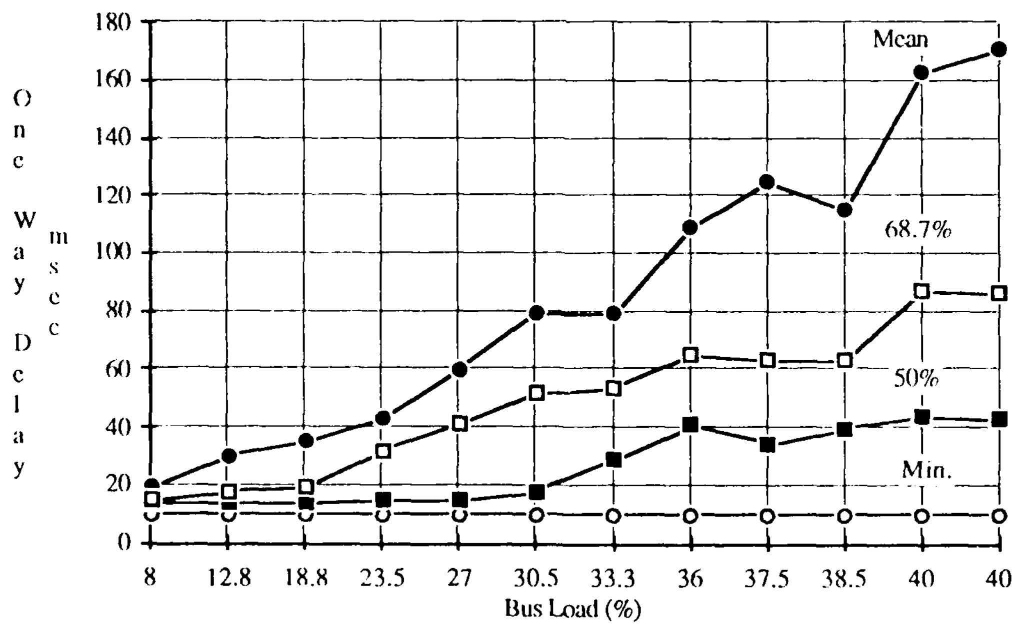
Test 33

Background Traffic (vc's)	25% Bridged Bus Load (%)	75% Unbridged Bus Load (%)	Mean Delay (msec)	Min. Delay (msec)	<=50% Delay (msec)	<=68.7% Delay (msec)	<=99.9% Delay (msec)	Max. Delay (msec)	Total Characters Transferred
12	4	8	19	10	14	15	302	432	1004
24	5	12.8	30	10	14	18	507	1035	1001
36	5.5	18.8	35	10	14	19	603	662	1005
48	6.3	23.5	43	10	15	32	1284	1745	1002
60	8.5	27	60	10	15	41	1547	2035	1004
72	9.3	30.5	79	10	18	52	2286	2301	1003
84	8.5	33.3	79	10	29	54	1829	1829	1001
96	9	36	109	10	41	65	3180	3667	1002
107	10	37.5	125	10	34	63	2468	3649	1003
118	10	38.5	115	10	40	63	2921	3542	1002
130	10.5	40	163	10	44	87	3015	3323	1002
134	10.5	40	171	10	43	86	3438	3734	1003



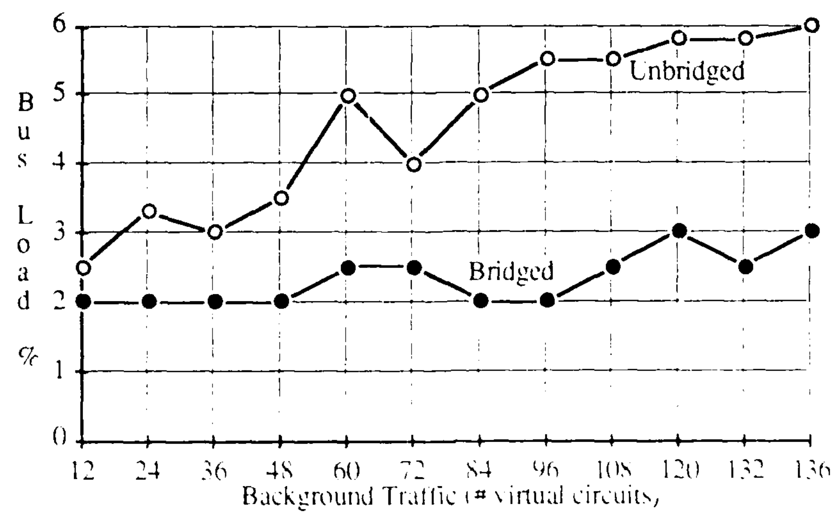
Test 33 (concluded)



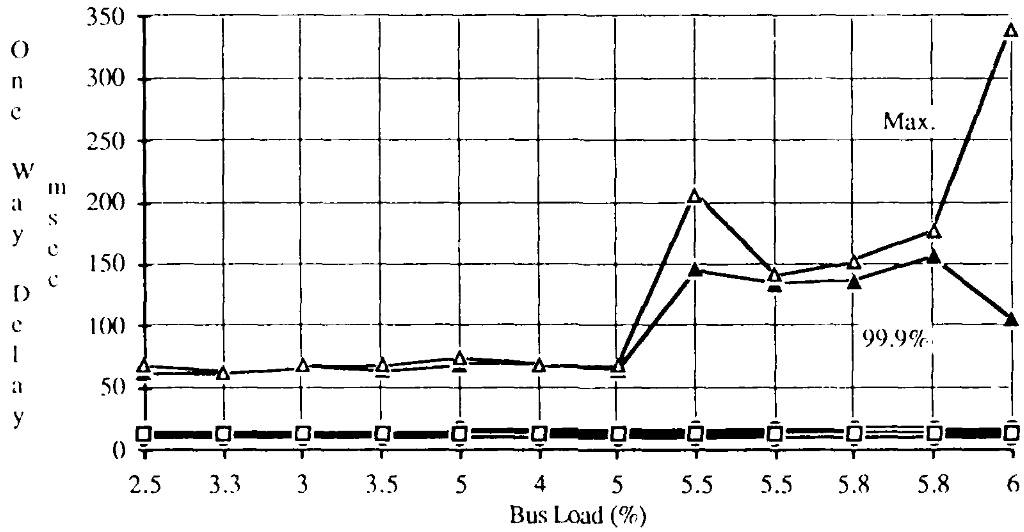


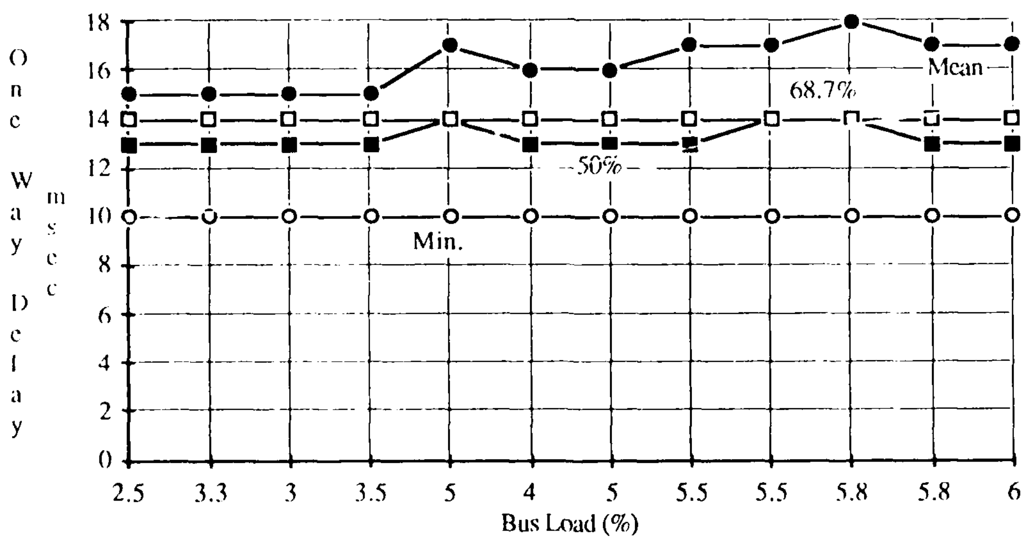
Test 34

Background Traffic (vc's)	25% Bridged Bus Load (%)	75% Unbridged Bus Load (%)	Mean Delay (msec)	Min. Delay (msec)	<=50% Delay (msec)	<=68.7% Delay (msec)	<=99.9% Delay (msec)	Max. Delay (msec)	Total Characters Transferred
12	2	2.5	15	10	13	14	63	69	1002
24	2	3.3	15	10	13	14	63	63	1003
36	2	3	15	10	13	14	69	69	1002
48	2	3.5	15	10	13	14	64	68	1003
60	2.5	5	17	10	14	14	70	75	1002
72	2.5	4	16	10	13	14	68	69	1003
84	2	5	16	10	13	14	65	68	1004
96	2	5.5	17	10	13	14	146	207	1003
108	2.5	5.5	17	10	14	14	135	142	1003
120	3	5.8	18	10	14	14	137	154	1001
132	2.5	5.8	17	10	13	14	157	178	1002
136	3	6	17	10	13	14	106	340	1005



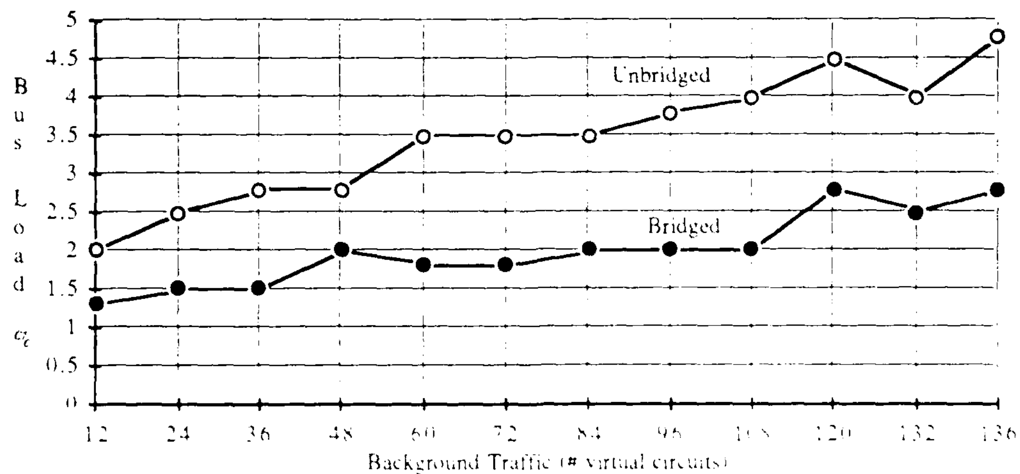
Test 34 (concluded)



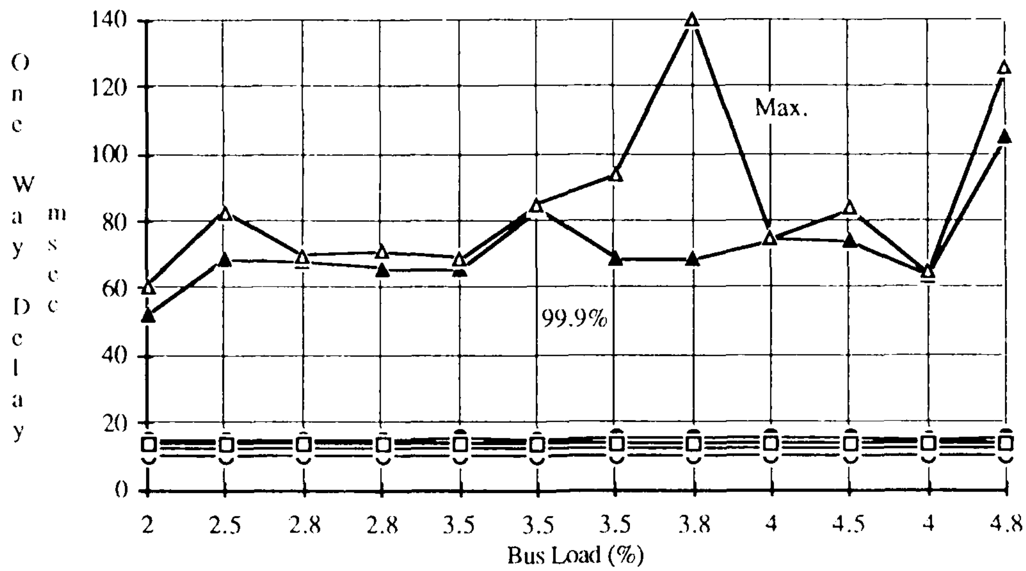


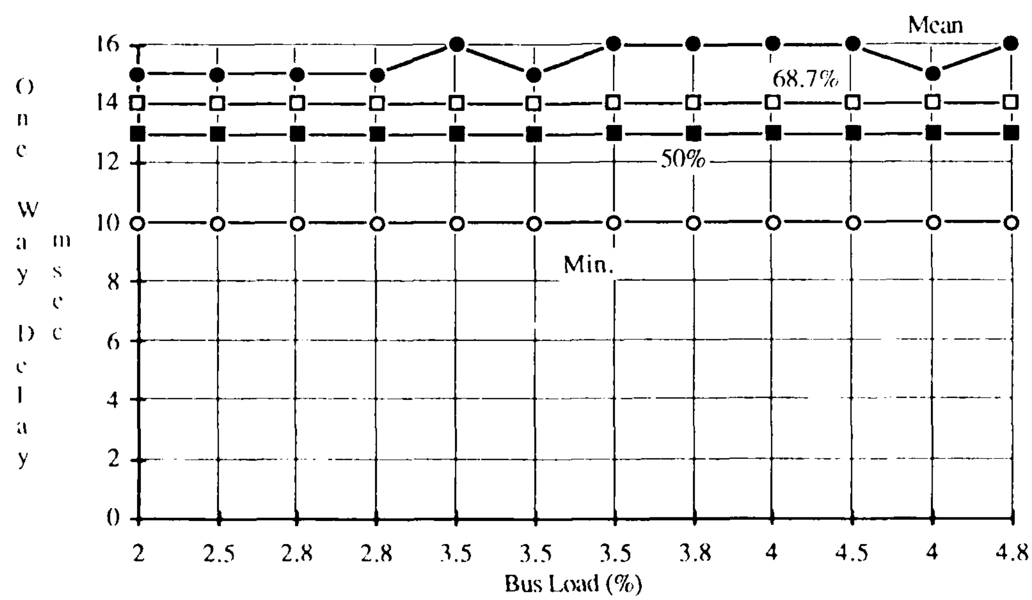
Test 35

Background Traffic (vc's)	25% Bridged Bus Load (%)	75% Unbridged Bus Load (%)	Mean Delay (msec)	Min. Delay (msec)	<=50% Delay (msec)	<=68.7% Delay (msec)	<=99.9% Delay (msec)	Max. Delay (msec)	Total Characters Transferred
12	1.3	2	15	10	13	14	52	61	1003
24	1.5	2.5	15	10	13	14	69	83	1004
36	1.5	2.8	15	10	13	14	68	70	1003
48	2	2.8	15	10	13	14	66	71	1002
60	1.8	3.5	16	10	13	14	66	69	1003
72	1.8	3.5	15	10	13	14	84	85	1003
84	2	3.5	16	10	13	14	69	94	1001
96	2	3.8	16	10	13	14	69	140	1003
108	2	4	16	10	13	14	75	75	1001
120	2.8	4.5	16	10	13	14	74	84	1003
132	2.5	4	15	10	13	14	64	65	1003
136	2.8	4.8	16	10	13	14	105	126	1003



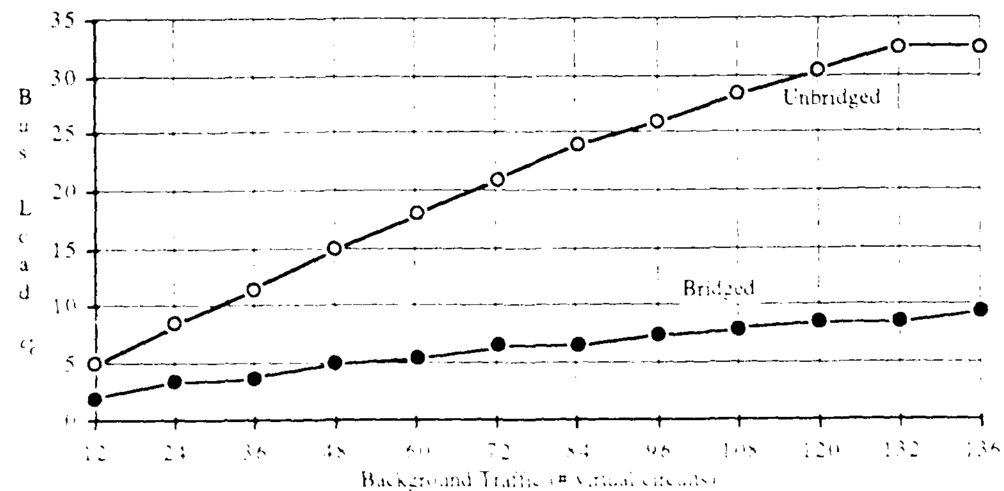
Test 35 (concluded)



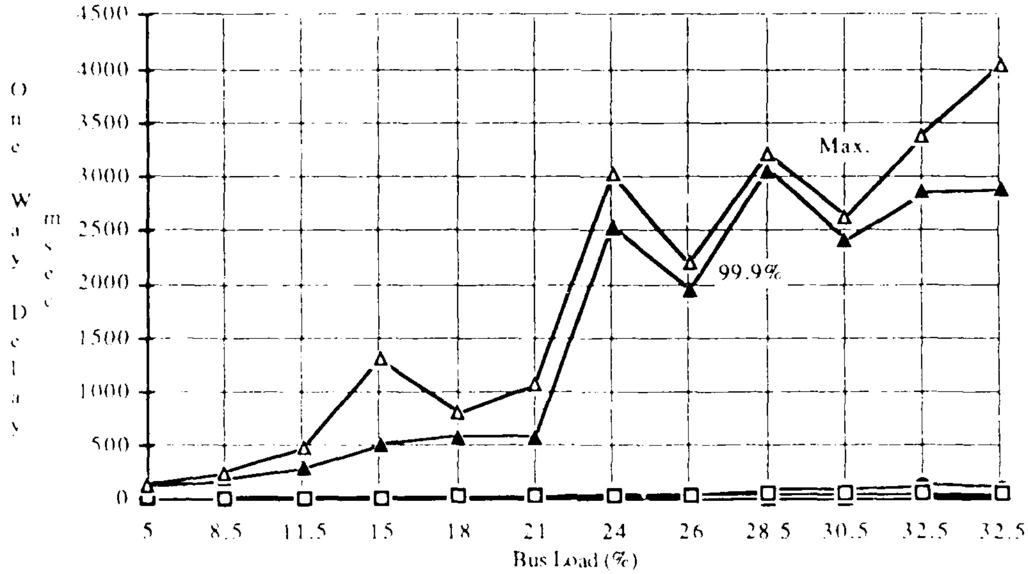


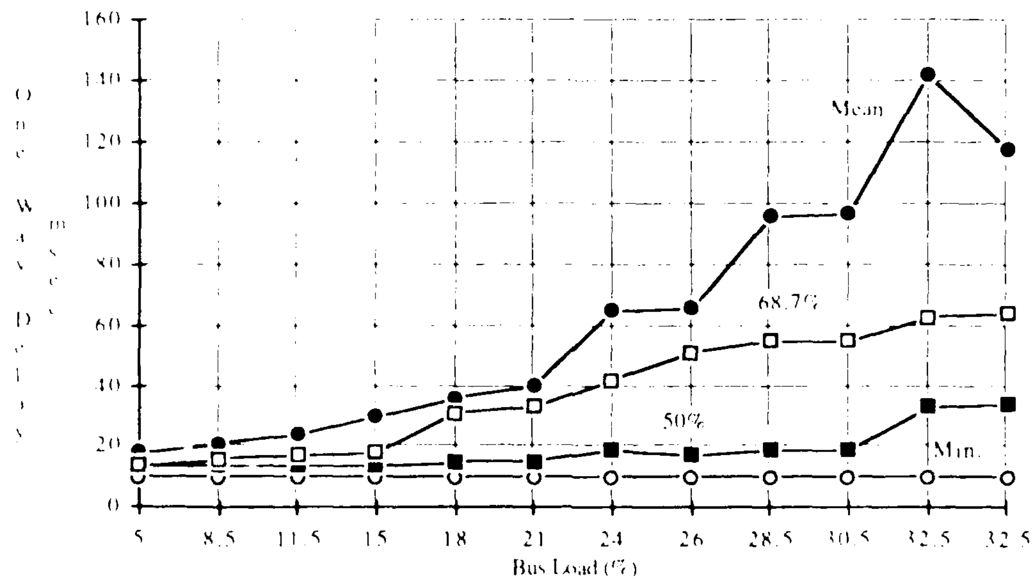
Test 36

Background Traffic (vc's)	25% Bridged Bus Load (%)	75% Unbridged Bus Load (%)	Mean Delay (msec)	Min. Delay (msec)	<=50% Delay (msec)	<=68.7% Delay (msec)	<=99.9% Delay (msec)	Max. Delay (msec)	Total Characters Transferred
12	2	5	18	10	14	14	134	146	1003
24	3.5	8.5	21	10	14	16	197	259	1002
36	3.8	11.5	24	10	14	17	298	480	1004
48	5	15	30	10	14	18	520	1306	1003
60	5.5	18	36	10	15	31	591	813	1001
72	6.5	21	40	10	15	33	591	1085	1006
84	6.5	24	65	10	19	42	2548	3037	1005
96	7.5	26	66	10	17	51	1947	2211	1002
108	8	28.5	96	10	19	55	3061	3212	1002
120	8.5	30.5	97	10	19	55	2417	2629	1007
132	8.5	32.5	142	10	33	63	2860	3398	1004
136	9.5	32.5	118	10	34	64	2893	4057	1002



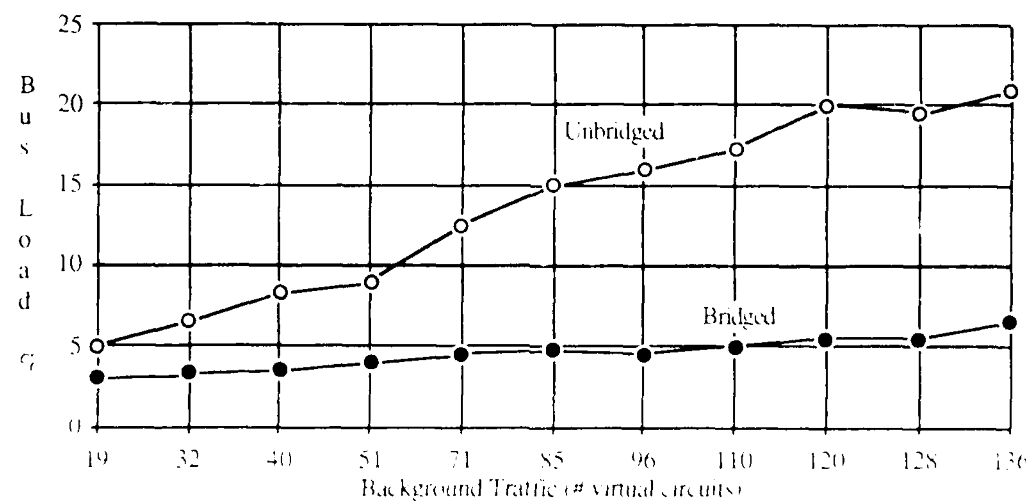
Test 36 (concluded)



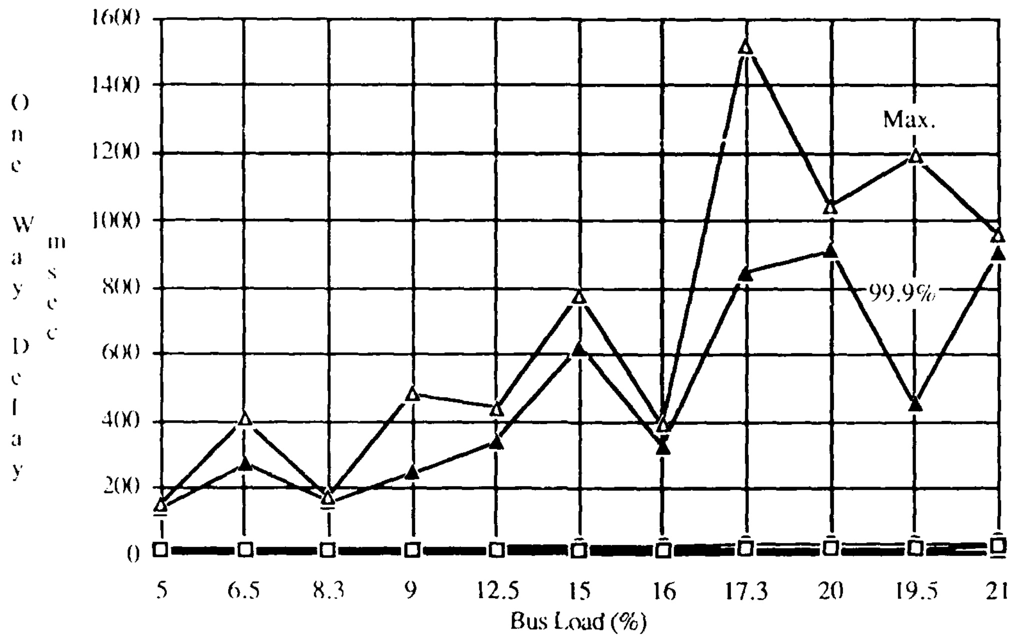


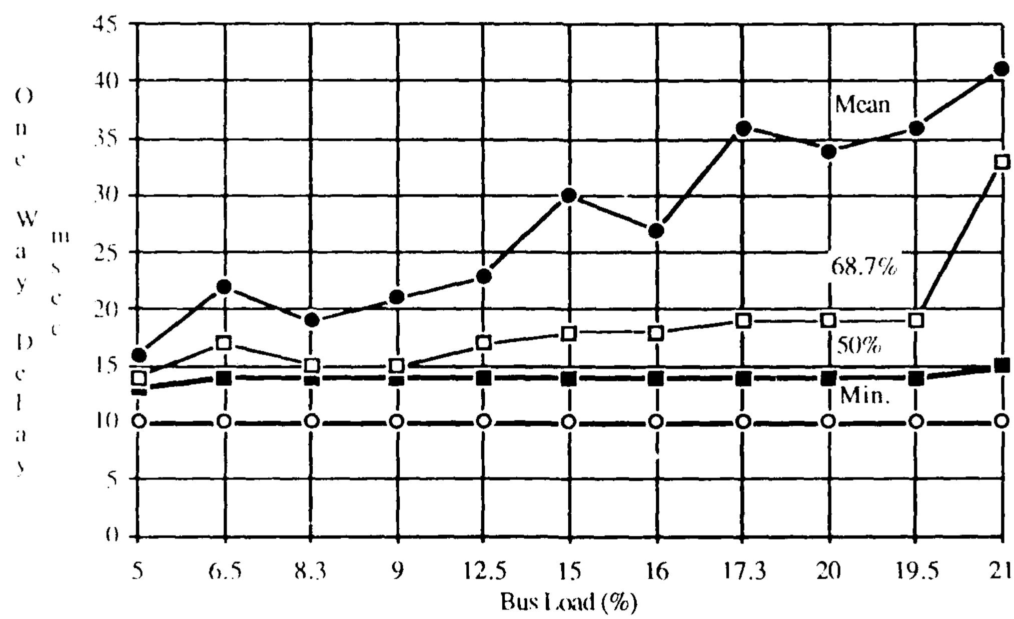
Test 37

Background Traffic (vc's)	25% Load Bridged (%)	75% Load Local (%)	Mean Delay (msec)	Min. Delay (msec)	<=50% Delay (msec)	<=68.7% Delay (msec)	<=99.9% Delay (msec)	Max. Delay (msec)	Total Characters Transferred
19	3	5	16	10	13	14	137	152	1004
32	3.3	6.5	22	10	14	17	272	404	1004
40	3.5	8.3	19	10	14	15	155	176	1003
51	4	9	21	10	14	15	248	479	1002
71	4.5	12.5	23	10	14	17	343	436	1004
85	4.8	15	30	10	14	18	621	777	1005
96	4.5	16	27	10	14	18	325	391	1003
110	5	17.3	36	10	14	19	847	1519	1004
120	5.5	20	34	10	14	19	913	1043	1003
128	5.5	19.5	36	10	14	19	452	1190	1003
136	6.5	21	41	10	15	33	909	962	1004



Test 37 (concluded)





GLOSSARY

Acronyms

AFLC	Air Force Logistics Command
AGC	Automatic gain control
ALC	Air Logistics Center
bps	Bits per second
COTS	Commercial off-the-shelf
cps	Characters per second
CRC	Cyclical redundancy check
CSMA	Carrier sense multiple access
ESD	Electronic Systems Division
LAN	Local area network
LMS	Logistics management systems
msec	Millisecond
Mbps	Million bits per second
NIU	Network interface unit
NRZI	Non-return to zero inverted
TCM	Technical control and monitoring
TRW IND	TRW Information Networks Division
TRW SEDD	TRW Systems Engineering and Development Division
µs	Microsecond
wpm	Words per minute